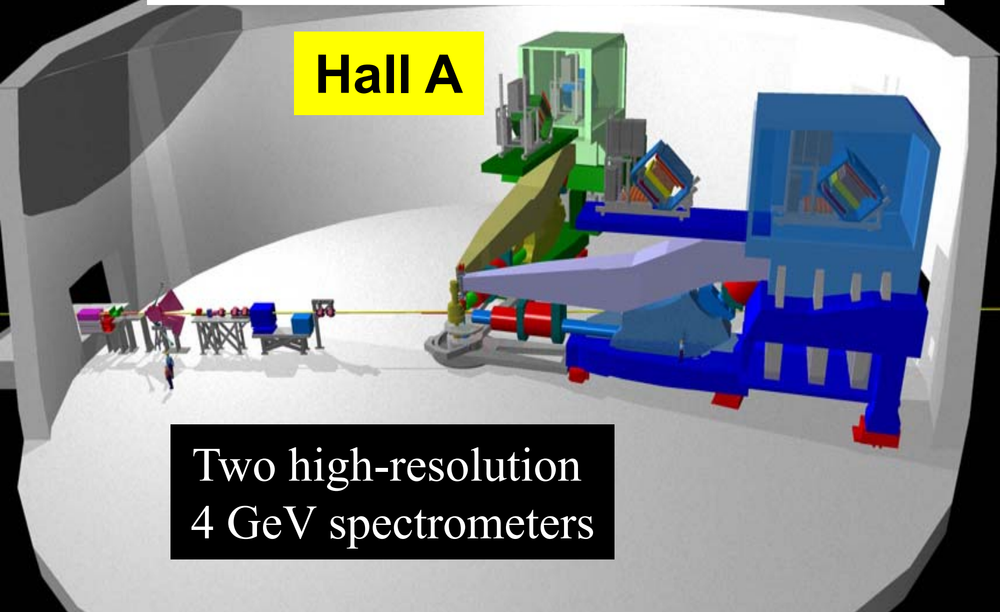
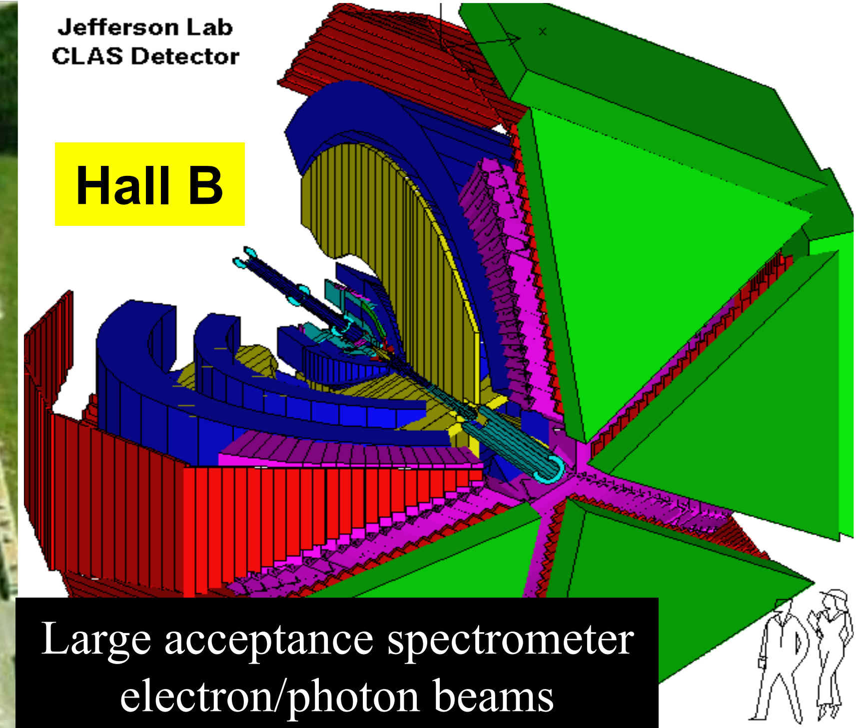
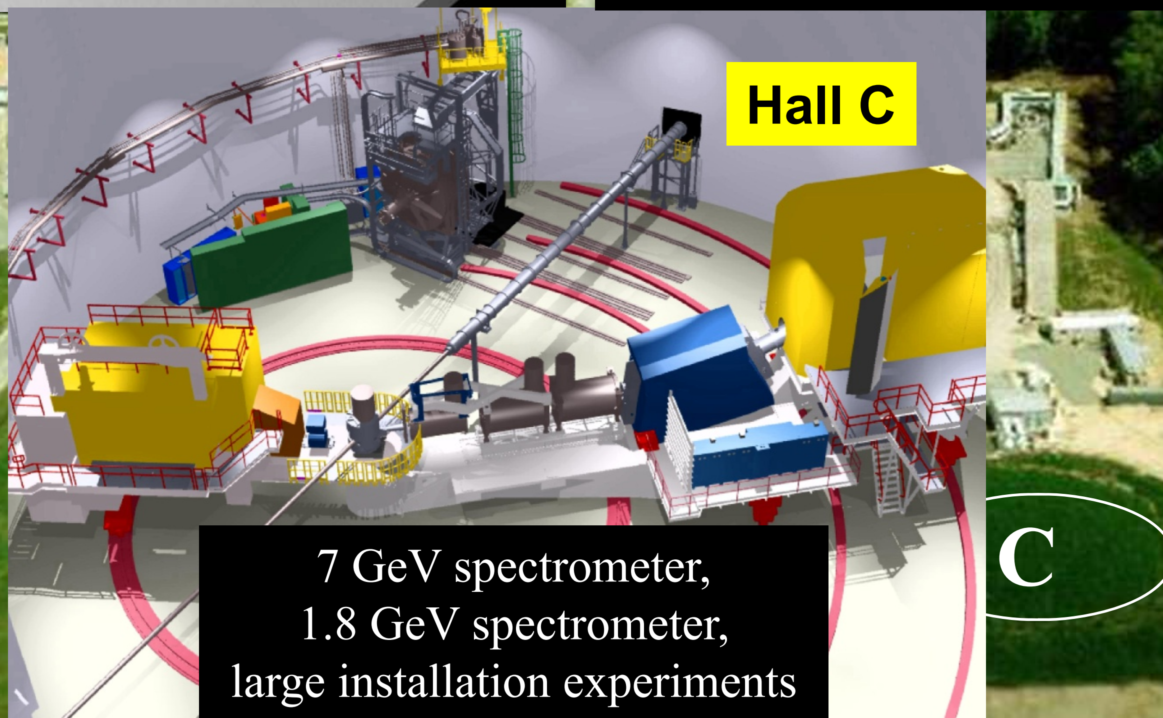
In the past few years, we were able to glimpse some of the new physics that is accessible through GPDs. However, much more experimental and theoretical work is needed to efficiently unravel the complex *structure* of the proton.

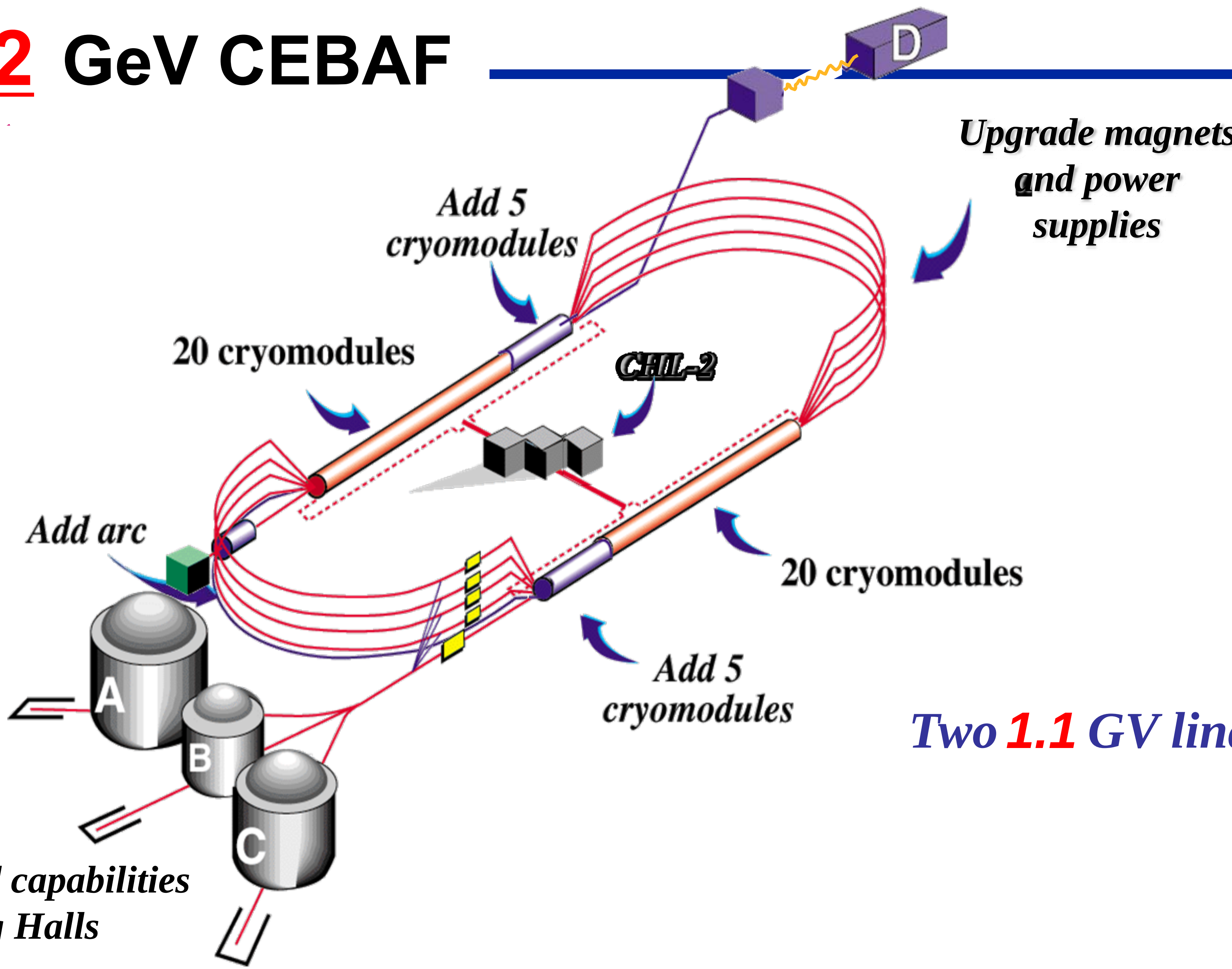
Jefferson Lab Today







12 GeV CEBAF

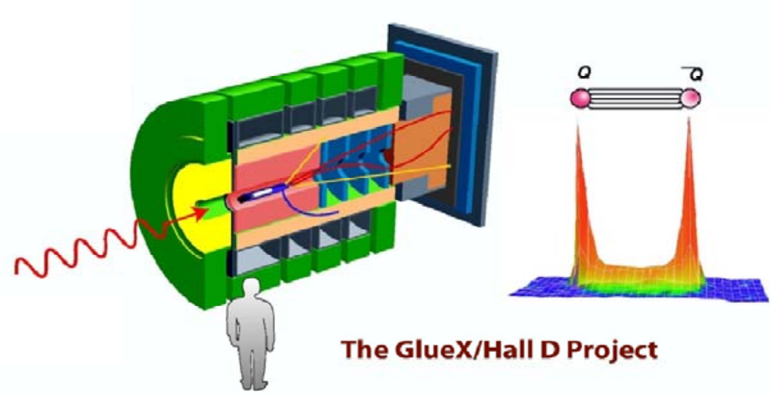


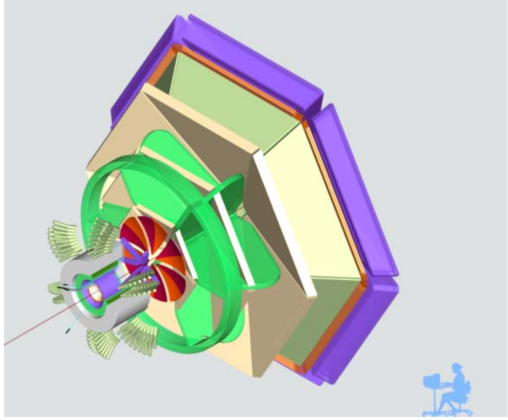
*Two **1.1** GV linacs*

Enhanced capabilities in existing Halls

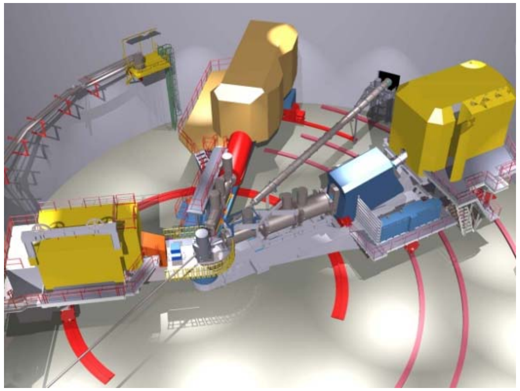
12 GeV Capabilities

Hall D – exploring origin of confinement by studying exotic mesons

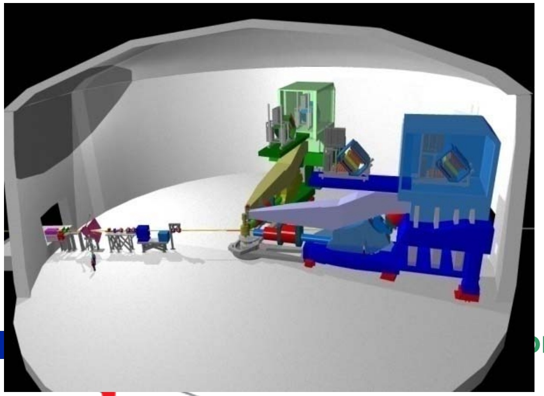




Hall B – understanding nucleon structure via generalized parton distributions

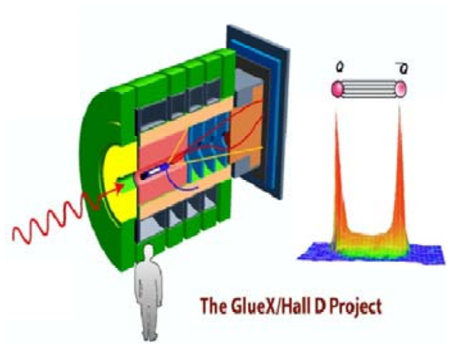


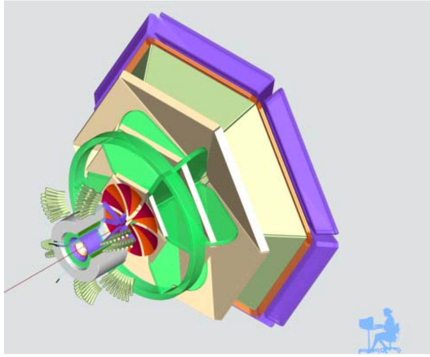
Hall C – precision determination of valence quark properties in nucleons and nuclei

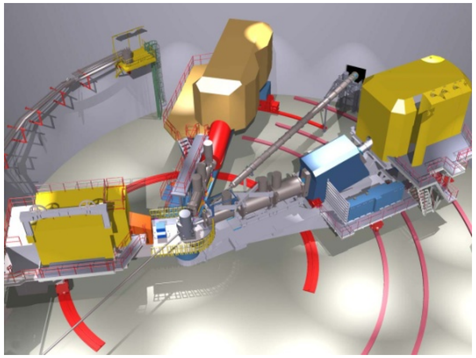


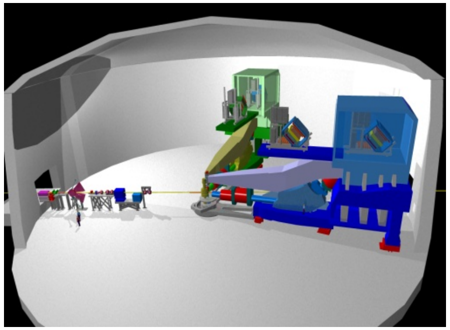
Hall A – short range correlations, form factors, hyper-nuclear physics, future new experiments

Overview of Upgrade Technical Performance Requirements



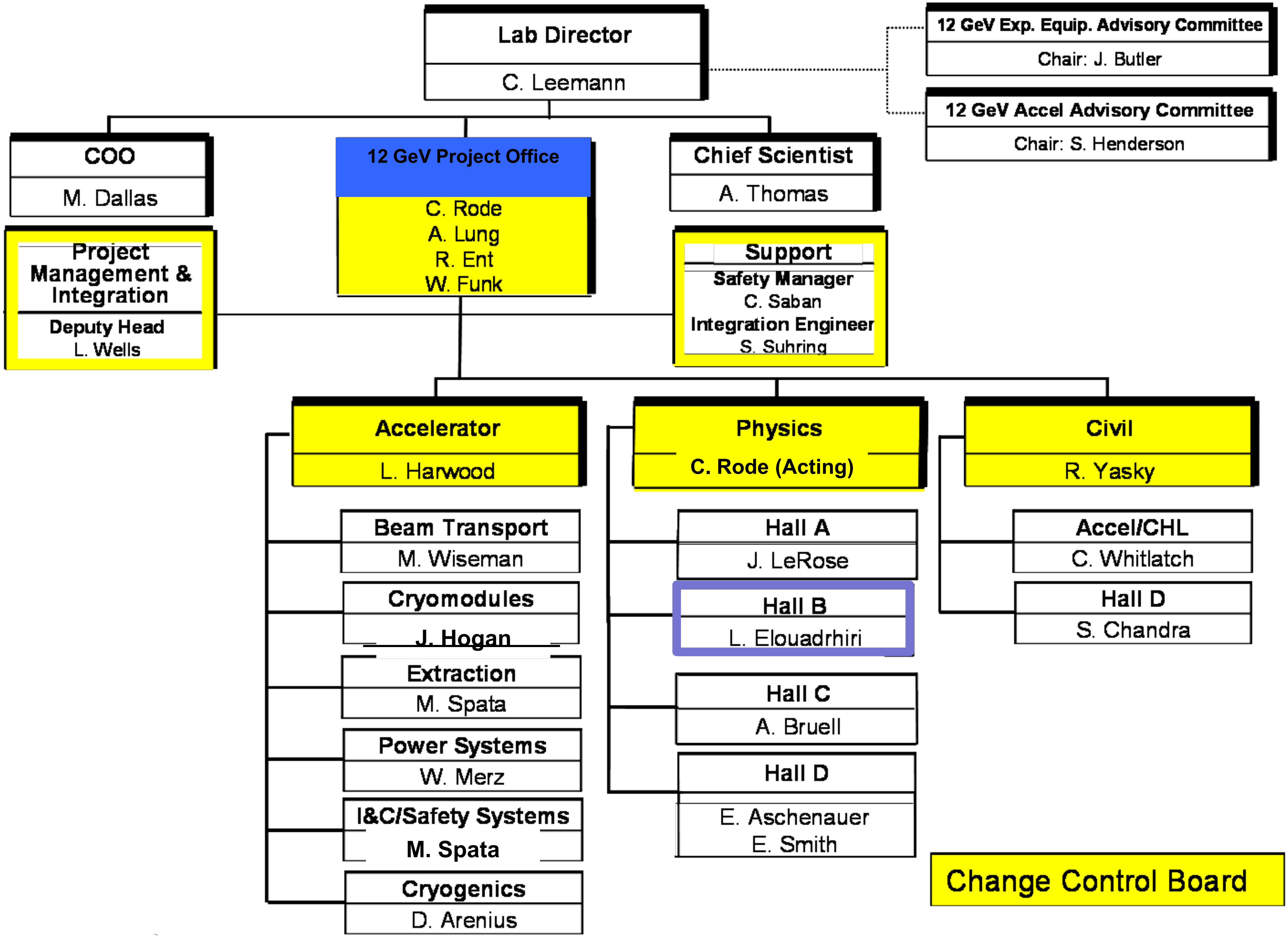






Hall D	Hall B	Hall C	Hall A
excellent hermeticity	luminosity 10^{35}	energy reach	installation space
polarized photons	hermeticity	precision	
E_γ~8.5–9 GeV	11 GeV beamline		
10^8 photons/s	target flexibility		
good momentum/angle resolution		excellent momentum resolution	
high multiplicity reconstruction		luminosity up to 10^{38}	
particle ID			

JLab 12 GeV Project Organization



DOE Generic Project Timeline

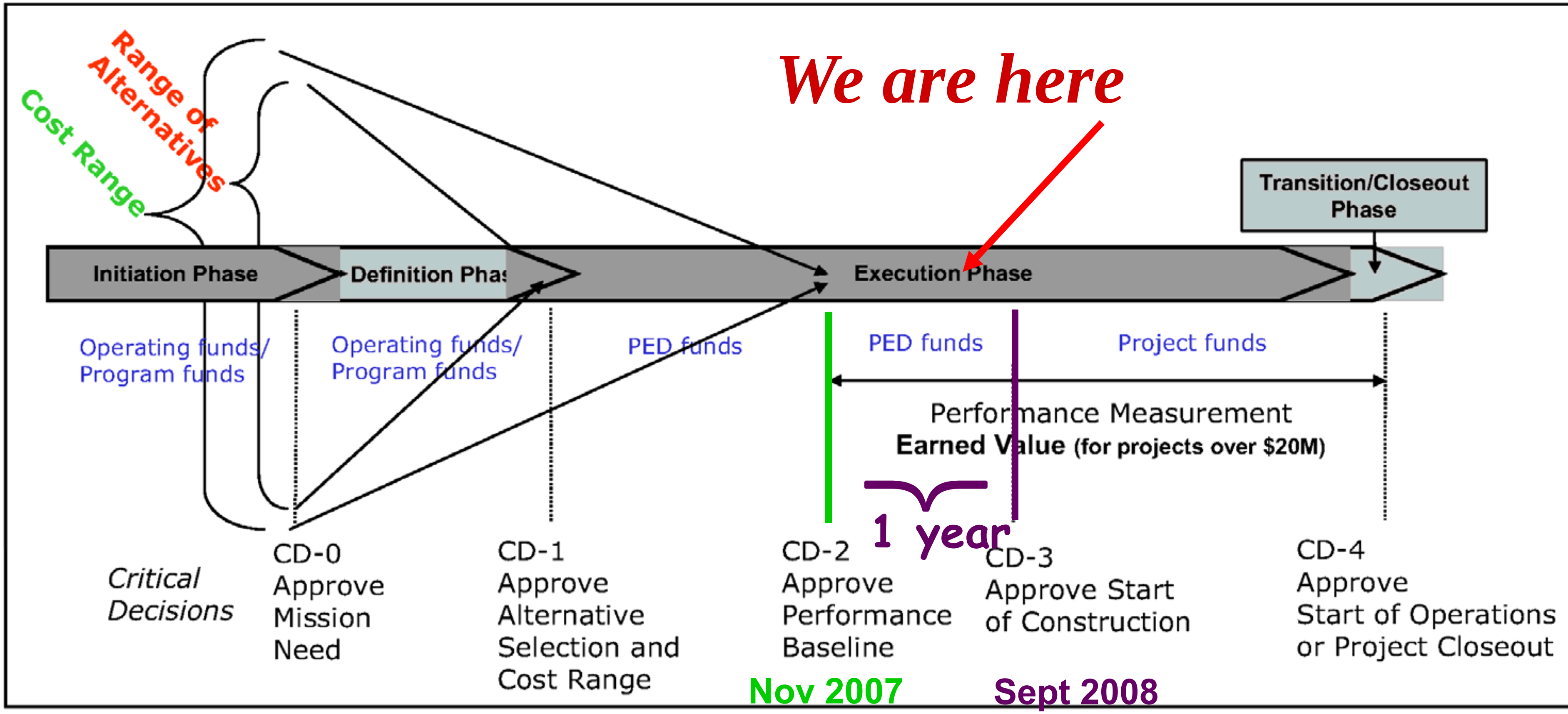


Figure 1-1. DOE Acquisition Management System.

DOE Project Critical Decisions

- **CD-0 Approve Mission Need**
- **CD-1 Approve Alternative Selection and Cost Range**
  - **Permission to develop a Conceptual Design Report**
  - **Defines a range of cost, scope, and schedule options**
- **CD-2 Approve Performance Baseline**
  - Fixes “baseline” for scope, cost, and schedule
  - Now develop design to 100%
  - Begin monthly Earned Value progress reporting to DOE
  - Permission for DOE-NP to request construction funds
- **CD-3 Approve Start of Construction**
- **CD-4 Approve Start of Operations or Project Close-out**

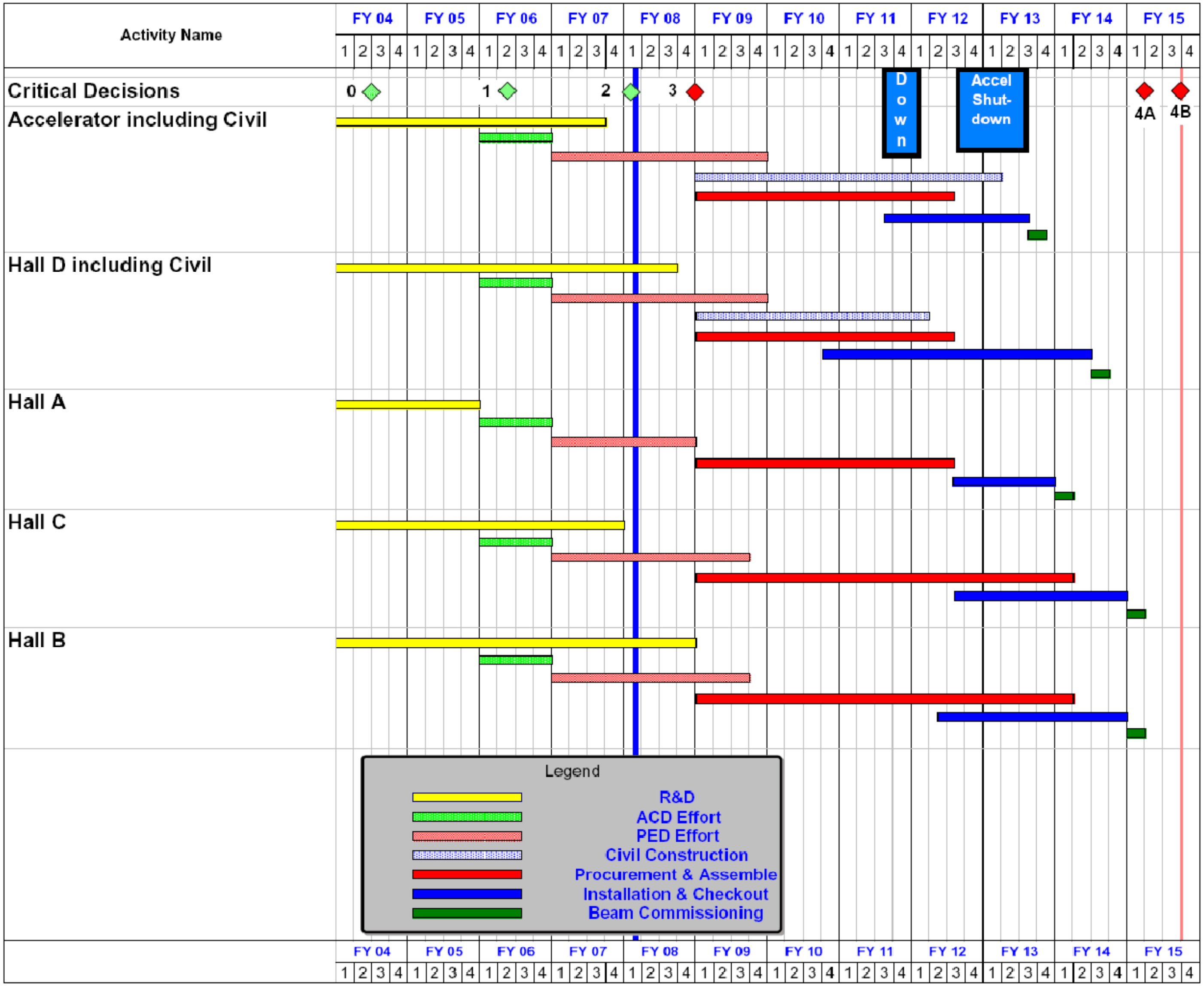
DOE CRITICAL DECISION SCHEDULE

CD-0 Mission Need	MAR-2004 (A)
CD-1 Preliminary Baseline Range	FEB-2006 (A)
CD-2 Performance Baseline	NOV-2007 (A)
CD-3 Start of Construction	SEP-2008
CD-4A Accelerator Project Completion and Start of Operations	DEC-2014
CD-4B Experimental Equipment Project Completion and Start of Operations	JUN-2015

CD-4 split in two to ease transition into operations phase

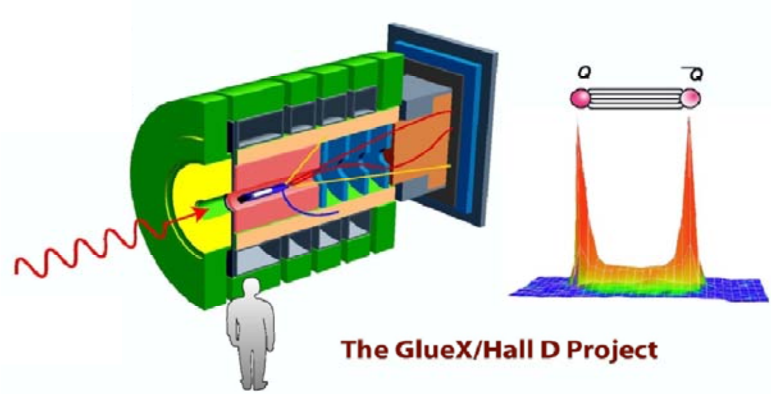
(A) = Actual Approval Date

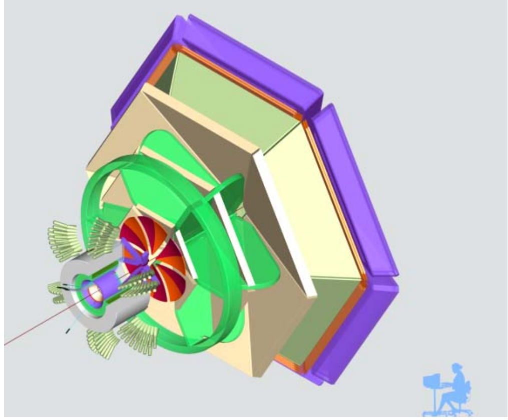
12 GeV UPGRADE SCHEDULE



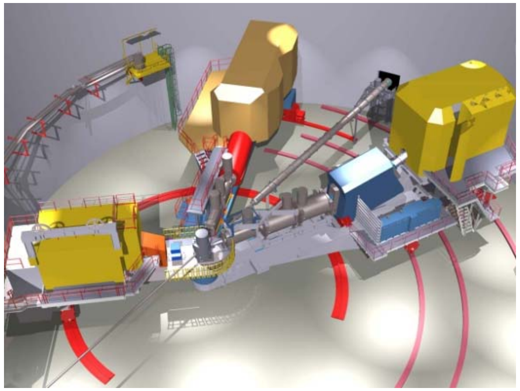
12 GeV Capabilities

Hall D – exploring origin of confinement by studying exotic mesons

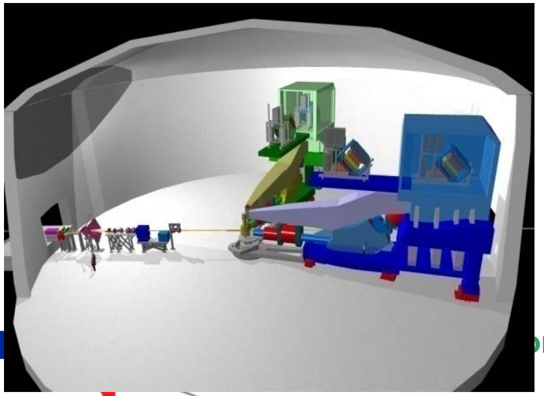




Hall B – understanding nucleon structure via generalized parton distributions

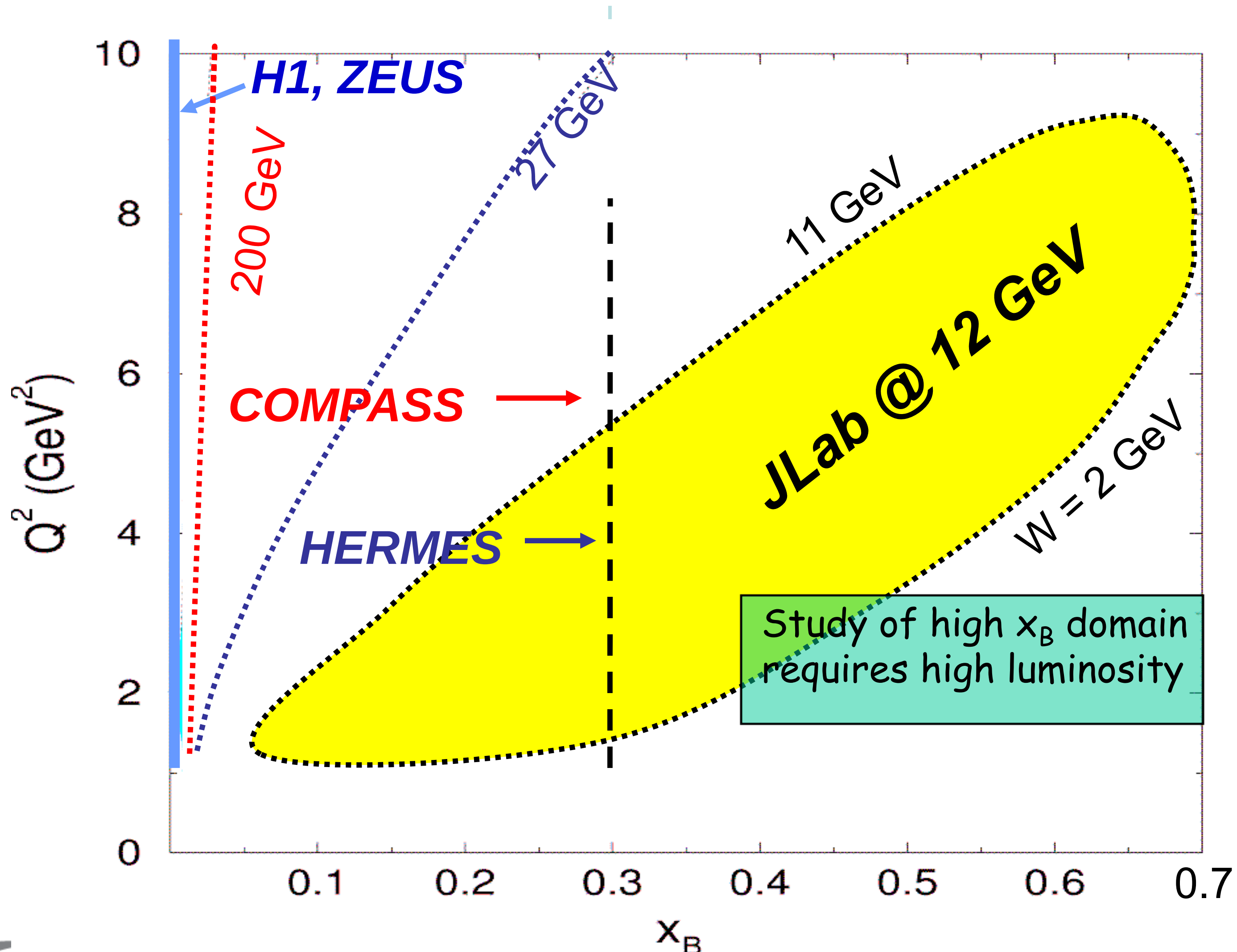


Hall C – precision determination of valence quark properties in nucleons and nuclei



Hall A – short range correlations, form factors, hyper-nuclear physics, future new experiments

Deeply Virtual Exclusive Processes - Kinematics Coverage of the 12 GeV Upgrade



Hall B Overview

• Hall B currently houses the **CLAS** detector. **CLAS** is a large acceptance detector and will be modified and upgraded to ***CLAS12,*** which will be worldwide the only large acceptance, multi-purpose detector for fixed target electron scattering experiments.

• ***CLAS12*** is expected to operate with an upgraded luminosity of $L=10^{35}cm^{-2}s^{-1}$, more than an order of magnitude increase over **CLAS**, and with improved particle identification.

• With these capabilities ***CLAS12*** will support a broad experimental program in fundamental nuclear physics.

Present-day CLAS

CLAS12 - Initial 12 GeV Physics Program

- **GPD's** and **3D-Imaging of the Nucleon**
  - Deeply Virtual Compton Scattering - DVCS
  - Deeply Virtual Meson Production at low/high t
- **Valence Quark Distributions**
  - u- and d-Quark Spin Distributions in Proton and Neutron
  - Neutron Structure Function $F_{2n}(x,Q^2)$, d/u
  - TMD Quark Distribution Functions in SIDIS
- **Form Factors and Resonance Excitations**
  - The Magnetic Structure of the Neutron – G_{Mn}
  - N* Transition Form Factors at high Q^2
- **Hadrons in the Nuclear Medium**
  - Space-Time Characteristics of Quark Hadronization
  - Color Transparency
  - Short Distance Dynamics of Light Nuclei
- **Spectroscopy of Strange Baryons**

CLAS12 - PAC approved proposals

Proposal	Physics	Experiment days
E12-06-119a	DVCS with polarized beam	80
E12-06-112	$ep \rightarrow e\pi^{+/-/0} X$	60
E12-06-108	DVMP in π^0,η production and L/T separation	120
E12-06-119b	DVCS on polarized target	120
E12-06- 109	Nucleon Spin Structure Functions	80
E12-07-107	Single Spin Asymmetries	103
E12-06-106	Color Transparency ρ^0	40
E12-06-117	Quark Hadronization	60
E12-07-104	Neutron magnetic form factor	56
Total		719

CLAS12 – Upgrade Goals

Capabilities to measure exclusive processes at 12 GeV

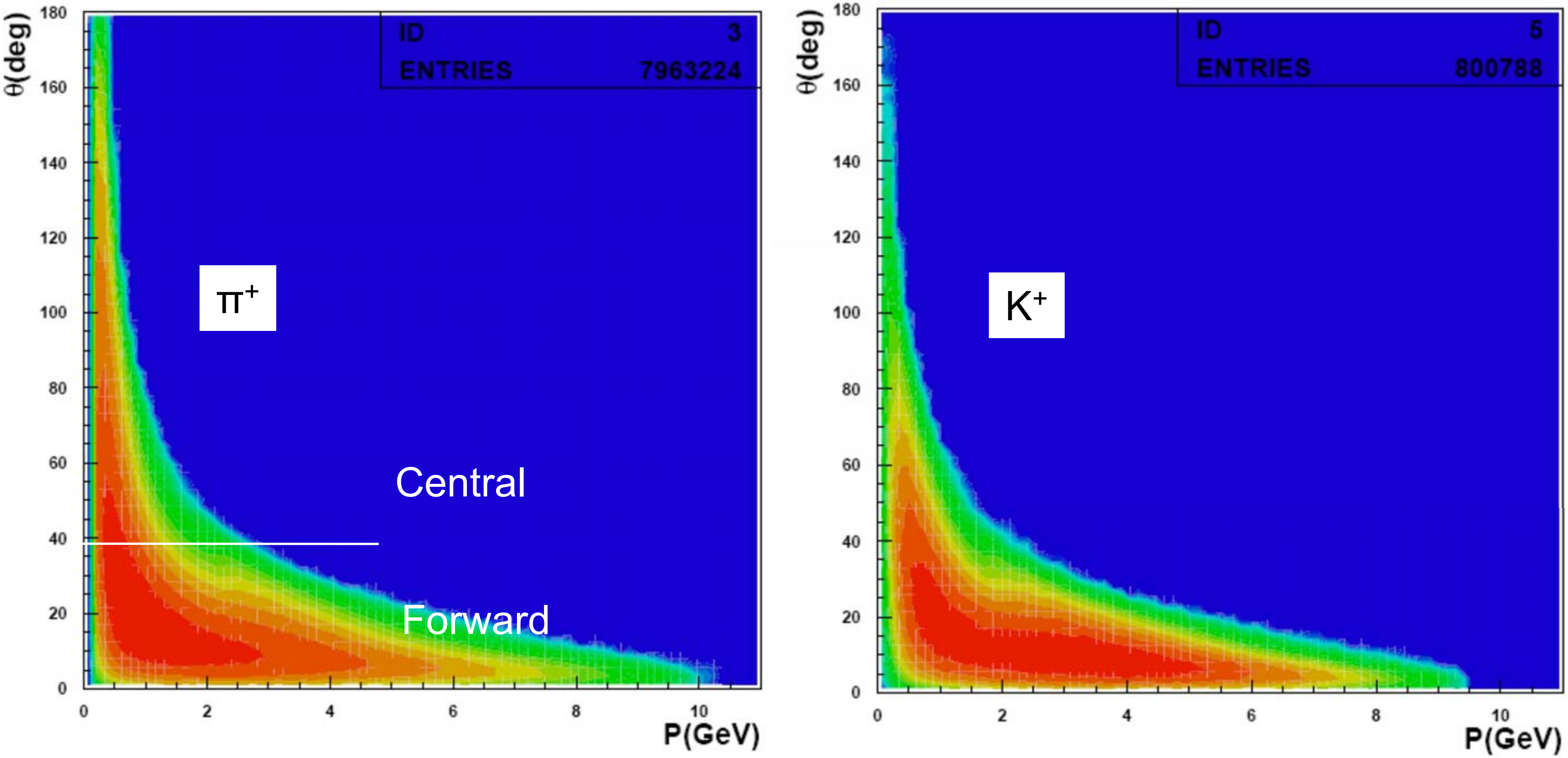
- Operating luminosity up to 10^{35} $cm^{-2}sec^{-1}$
- Particle ID to higher momentum (e^-/π^-, π/K-p, γ/π^o)
- Momentum & angle resolution for use of missing mass techniques
- Coverage of large range in polar and azimuth angle
- Identify detached vertices

Solution:

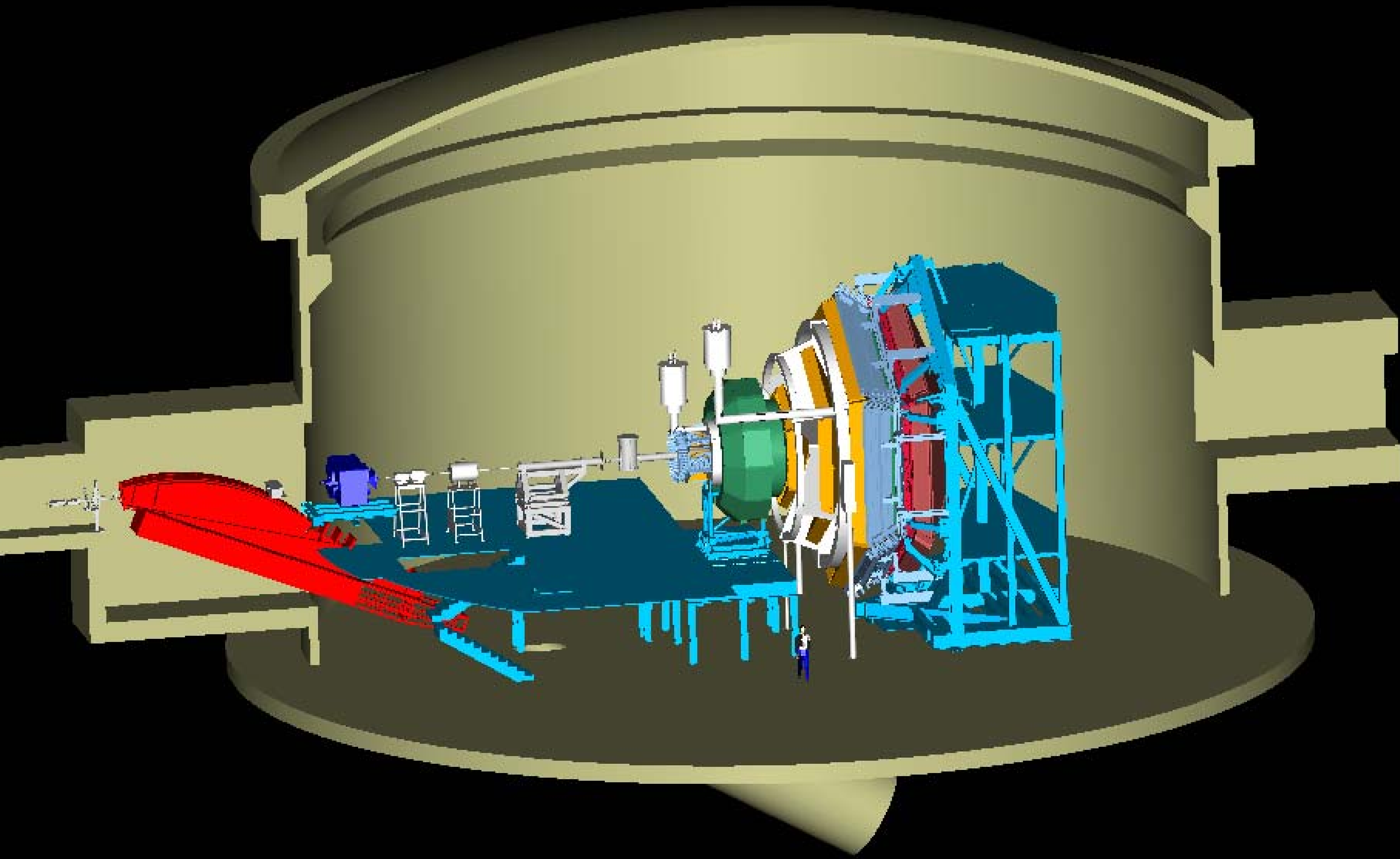
- Reduce DC occupancies to reach higher luminosities
  - Move DC's further downstream reducing solid angle seen by each cell
  - Improved magnetic shielding for Møller background electrons
- Upgrade the forward PID system
  - Additional threshold Cherenkov detector
  - Timing resolution of the Time-of-Flight detectors
  - Calorimeter granularity for π^o/γ separation
  - Add tracking capabilities for improved vertex resolution
- Complement the forward detection system with central detector
  - Tracking and magnetic analysis at large angles
  - Particle identification capabilities
  - Operation of a dynamically polarized target

Distribution of π⁺, K⁺ in DIS Kinematics

$e^- p \rightarrow e^- h X,\ h=\pi^+, K^+$



CLAS12 in Hall B

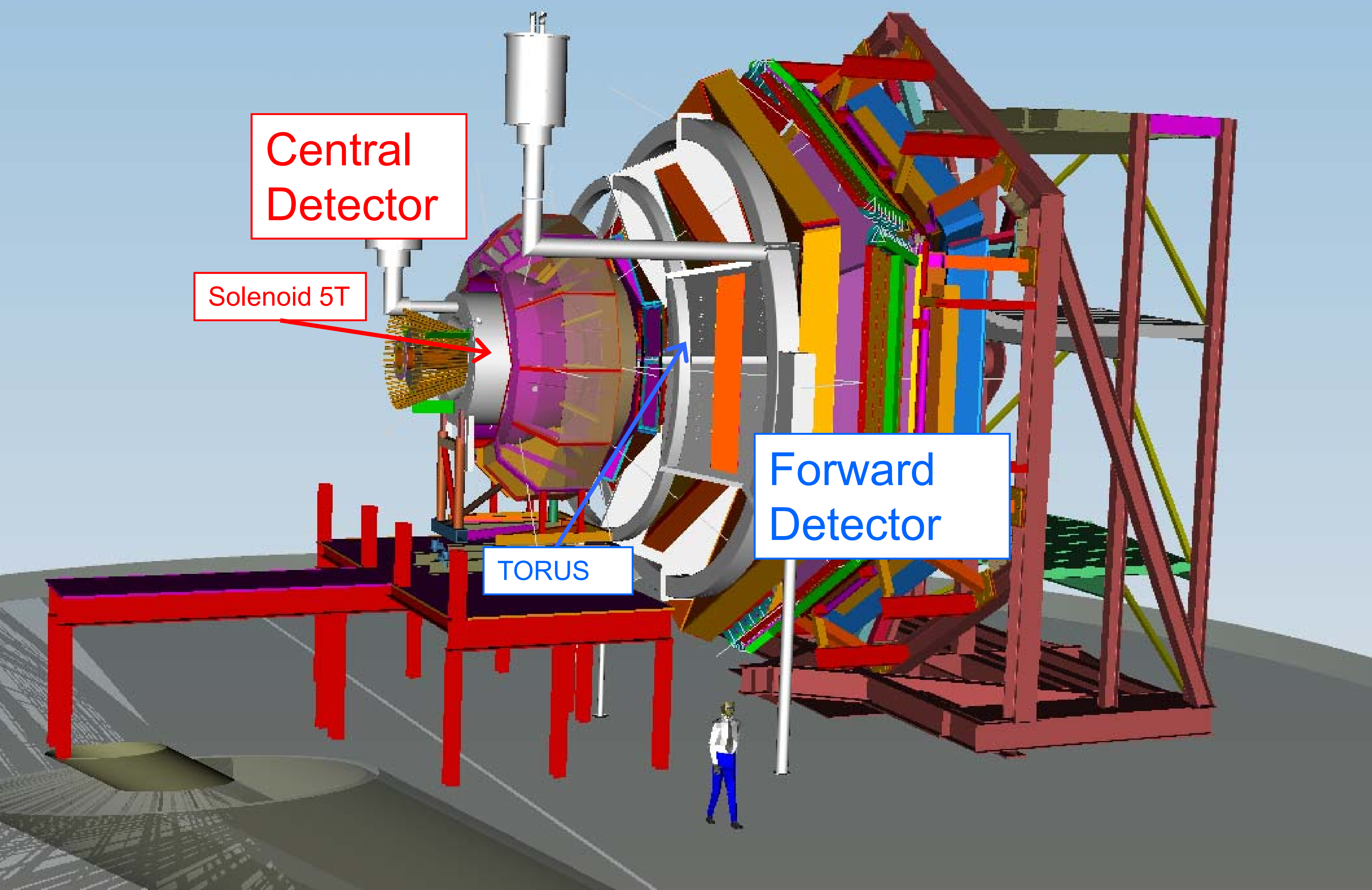


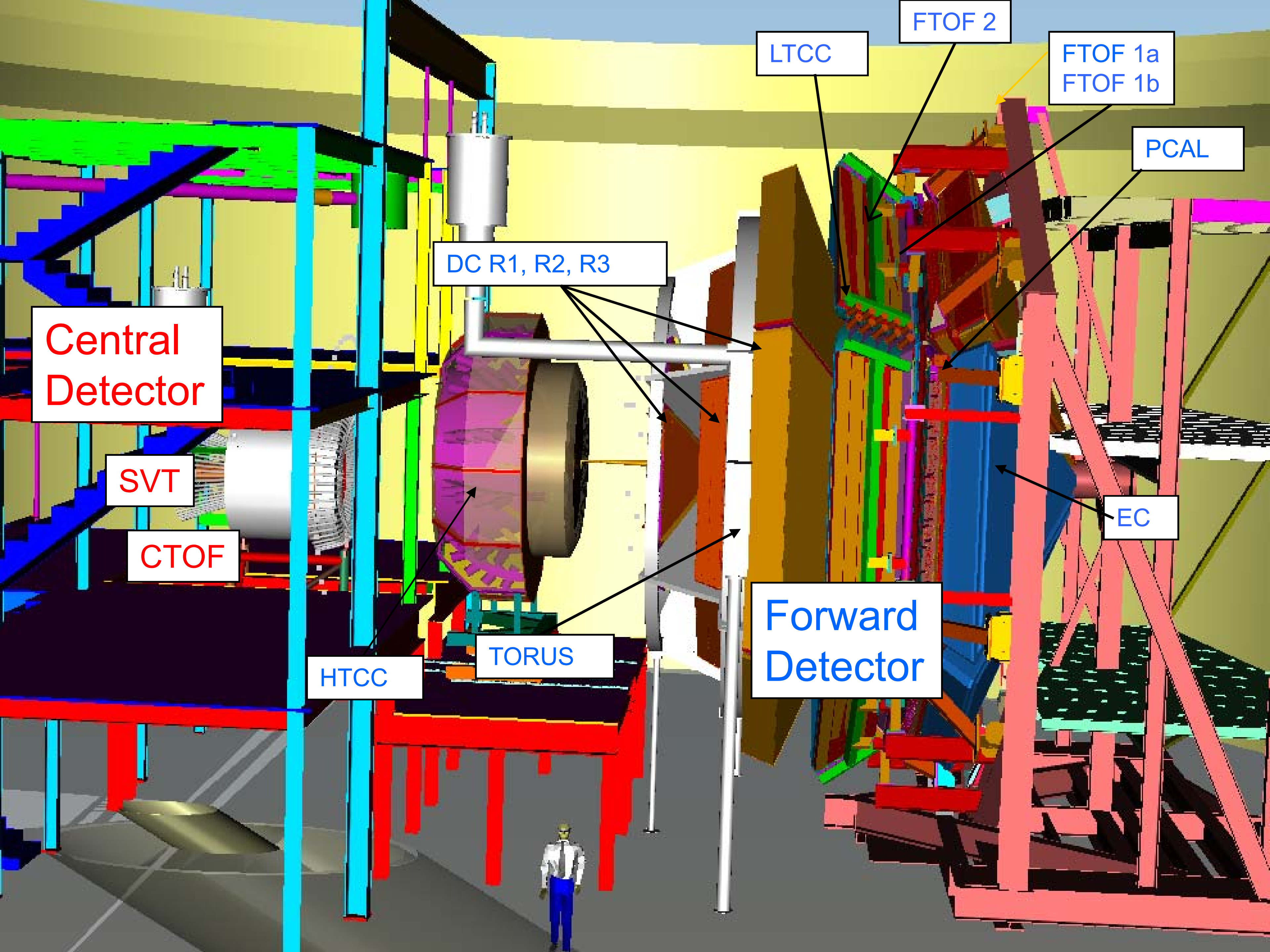
Utilization of existing Hall B Equipment

- Re-use existing CLAS detector components
  - Forward electromagnetic calorimeters
  - Low threshold gas Cherenkov counters
  - Time-of-flight scintillators
  - Drift chamber electronics and gas system
  - Inner $PbW0_4$ small-angle calorimeter
  - DAQ and readout electronics

- Re-use other Hall B components
  - Cryogenic targets
  - Møller polarimeter
  - Raster magnets & power supplies
  - Faraday cup
  - Beam diagnostics
  - Photon energy tagging system
  - Coherent bremsstrahlung/goniometer
  - Frozen spin polarized target
  - Pair spectrometer magnet & power supplies
  - Utility distribution & space frames

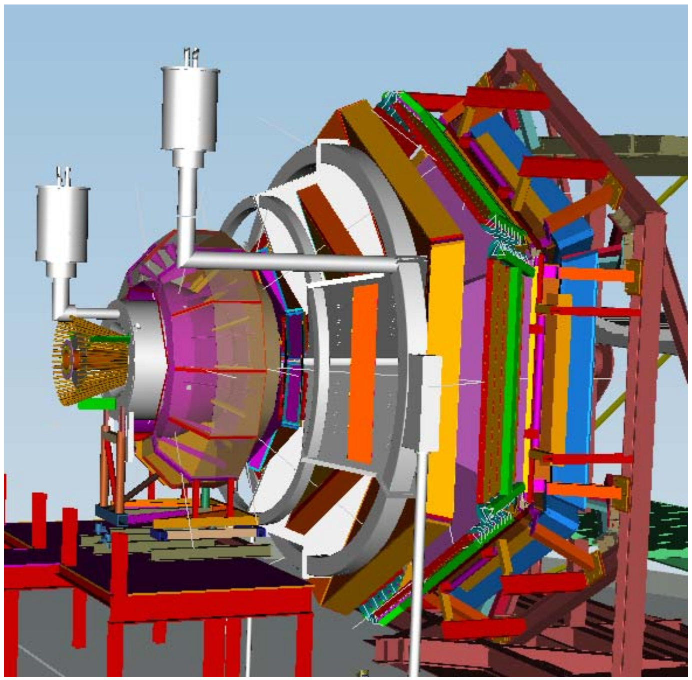
CLAS12 - Detector





FTOF 2
LTCC
FTOF 1a
FTOF 1b
PCAL
DC R1, R2, R3
Central
Detector
SVT
CTOF
EC
Forward
Detector
TORUS
HTCC

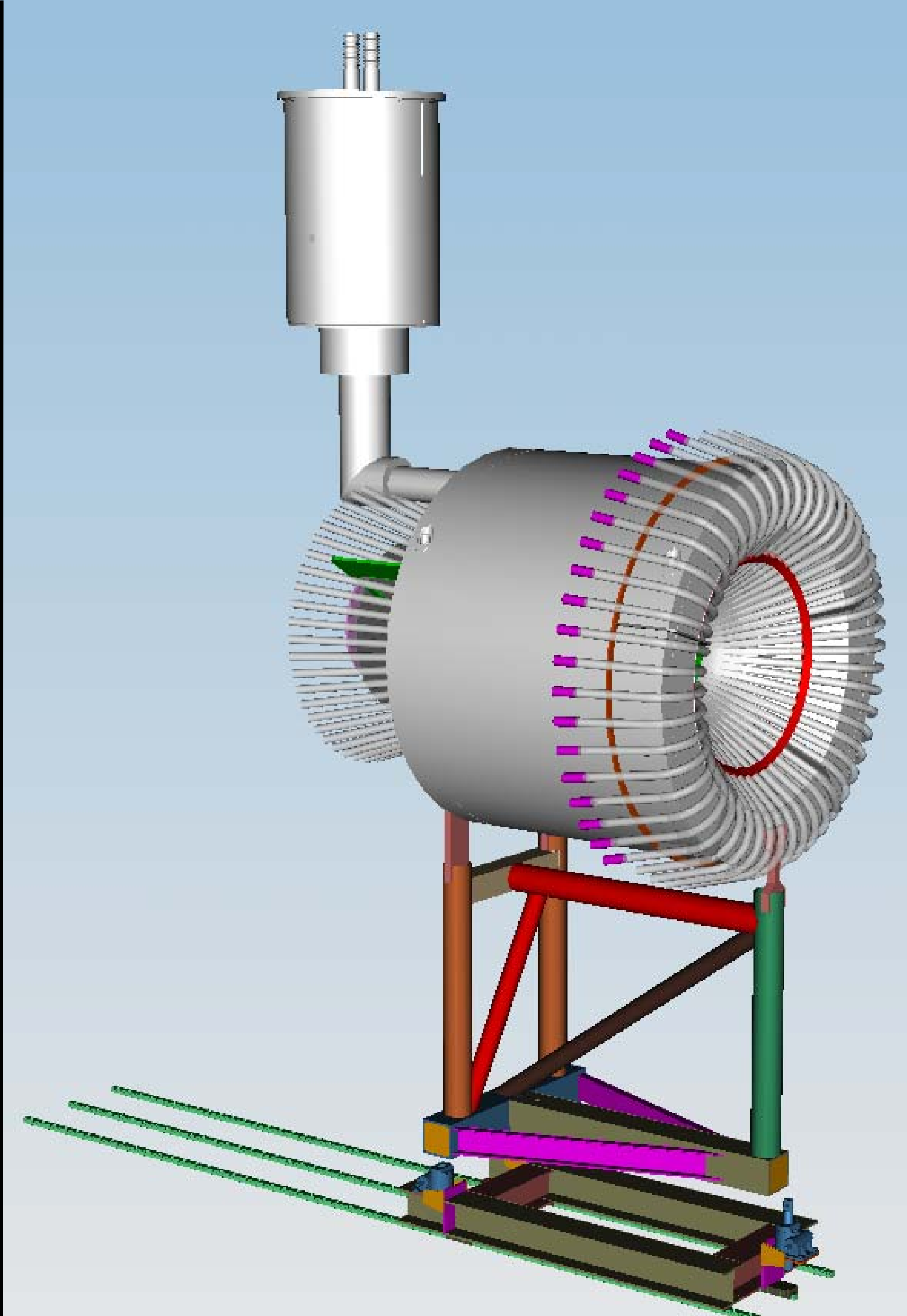
CLAS12 – Design Parameters

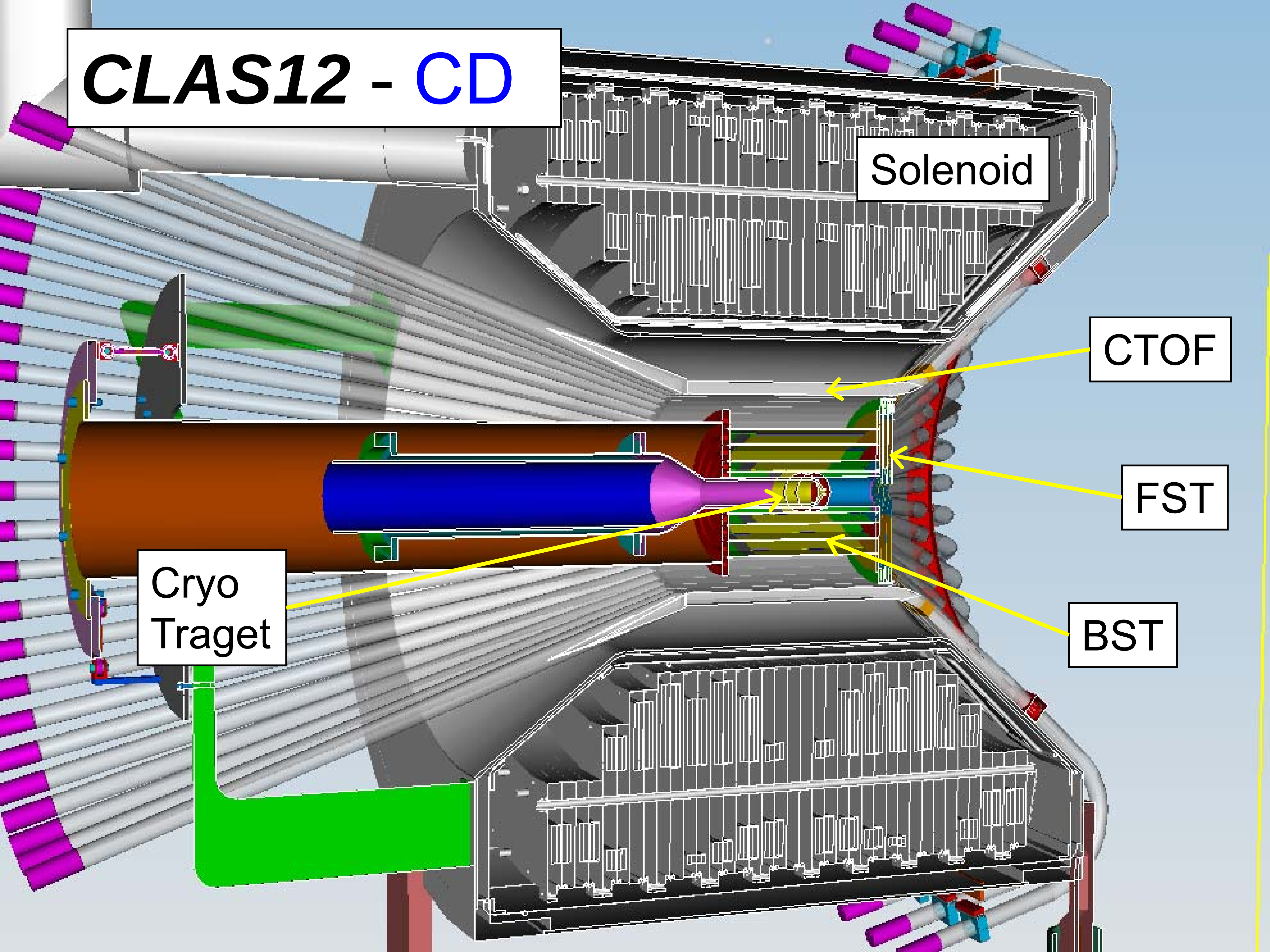


	Forward Detector	Central Detector
Angular range		
Tracks	$5^0 – 40^0$	$35^0 – 125^0$
Photons	$3^0 – 40^0$	n.a.
Resolution		
$\delta p/p$ (%)	< 1 @ 5 GeV/c	< 5 @ 1.5 GeV/c
$\delta\theta$ (mr)	< 1	< 10 - 20
$\Delta\phi$ (mr)	< 3	< 5
Photon detection		
Energy (MeV)	>150	n.a.
$\delta\theta$ (mr)	4 @ 1 GeV	n.a.
Neutron detection		
N_{eff}	< 0.7 (EC+PCAL)	n.a.
Particle ID		
e/π	Full range	n.a.
π/p	Full range	< 1.25 GeV/c
π/K	Full range	< 0.65 GeV/c
K/p	< 4 GeV/c	< 1.0 GeV/c
$\pi^0\rightarrow\gamma\gamma$	Full range	n.a.
$\eta\rightarrow\gamma\gamma$	Full range	n.a.

CLAS12 Central Detector

- Superconducting 5T Solenoid Magnet, w/ 78cm ø warm bore.
- Central scintillator array (CTOF).
- Silicon Vertex Tracker, barrel part (BST), forward part (FST).
- Space for cryogenic target.





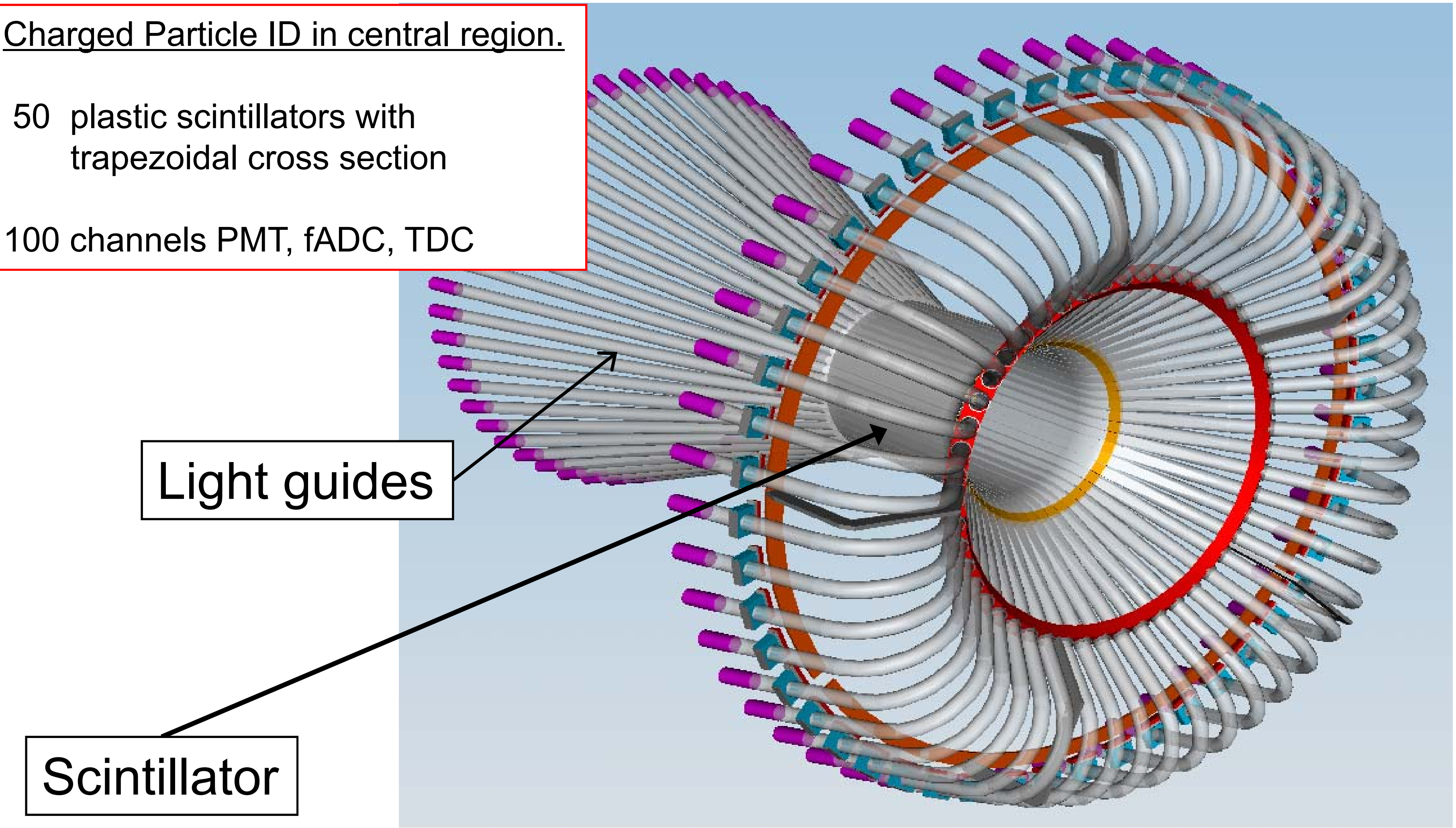
CLAS12 - CD
Solenoid
CTOF
FST
BST
Cryo Traget

CLAS12 - Central Time-of-Flight Counter

<u>Charged Particle ID in central region.</u>

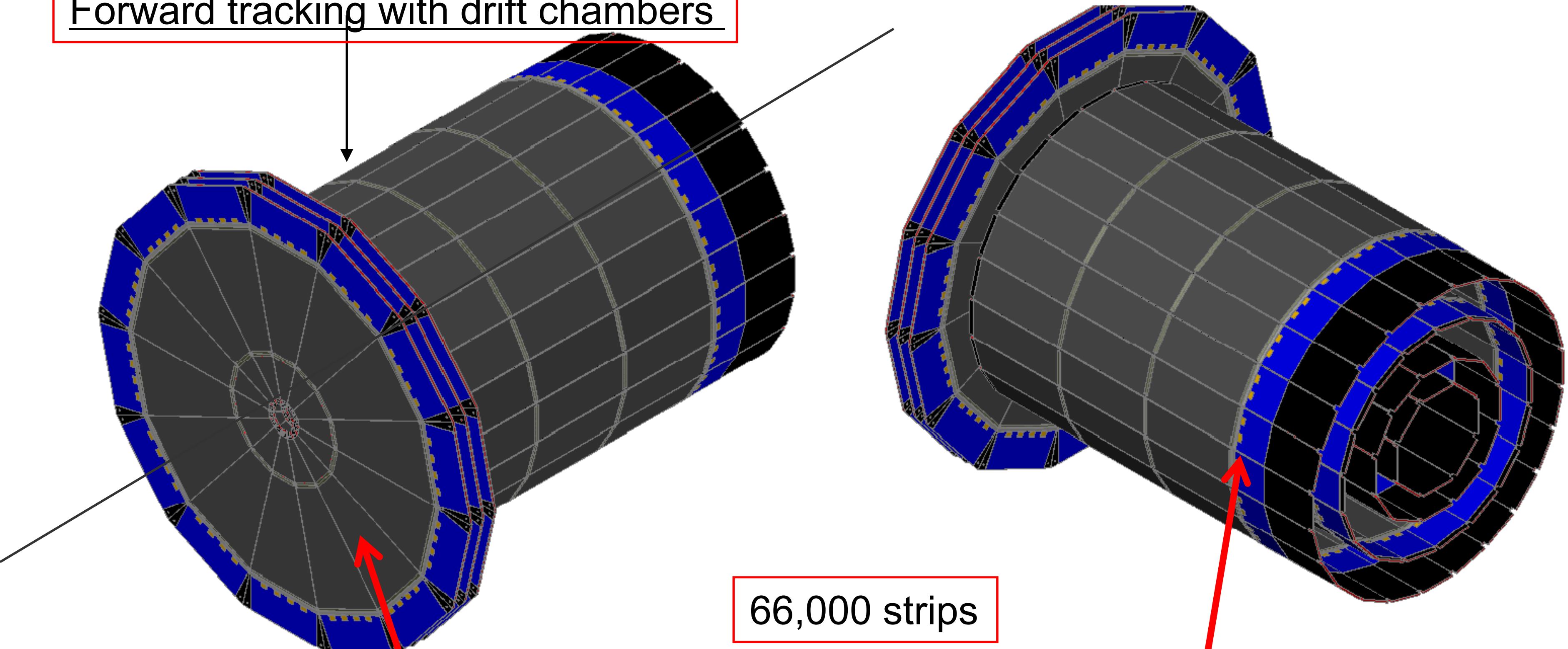
50 plastic scintillators with trapezoidal cross section

100 channels PMT, fADC, TDC



CLAS12 – Silicon Vertex Tracker

Central tracking in solenoid magnet
Forward tracking with drift chambers

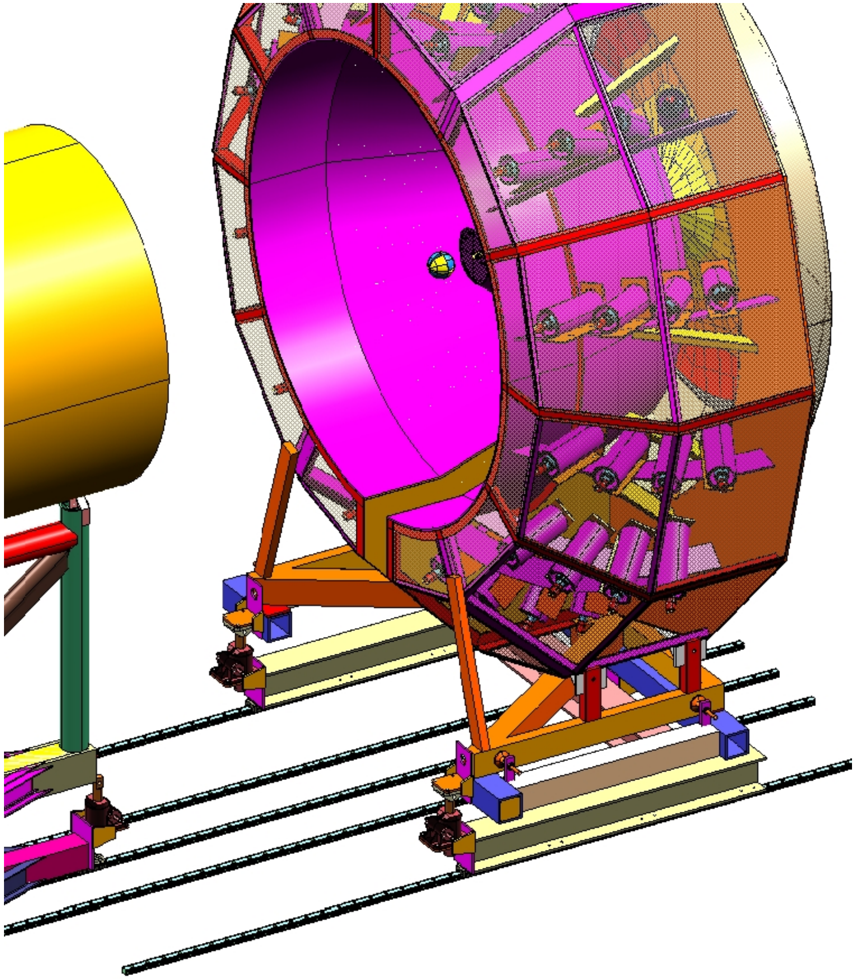


66,000 strips

Forward part, 6 stereo layers ±12°
With forward DC systems provide vertex

Barrel part, 8 stereo layers w/ 3°
Standalone Tracking in 5T magnetic field

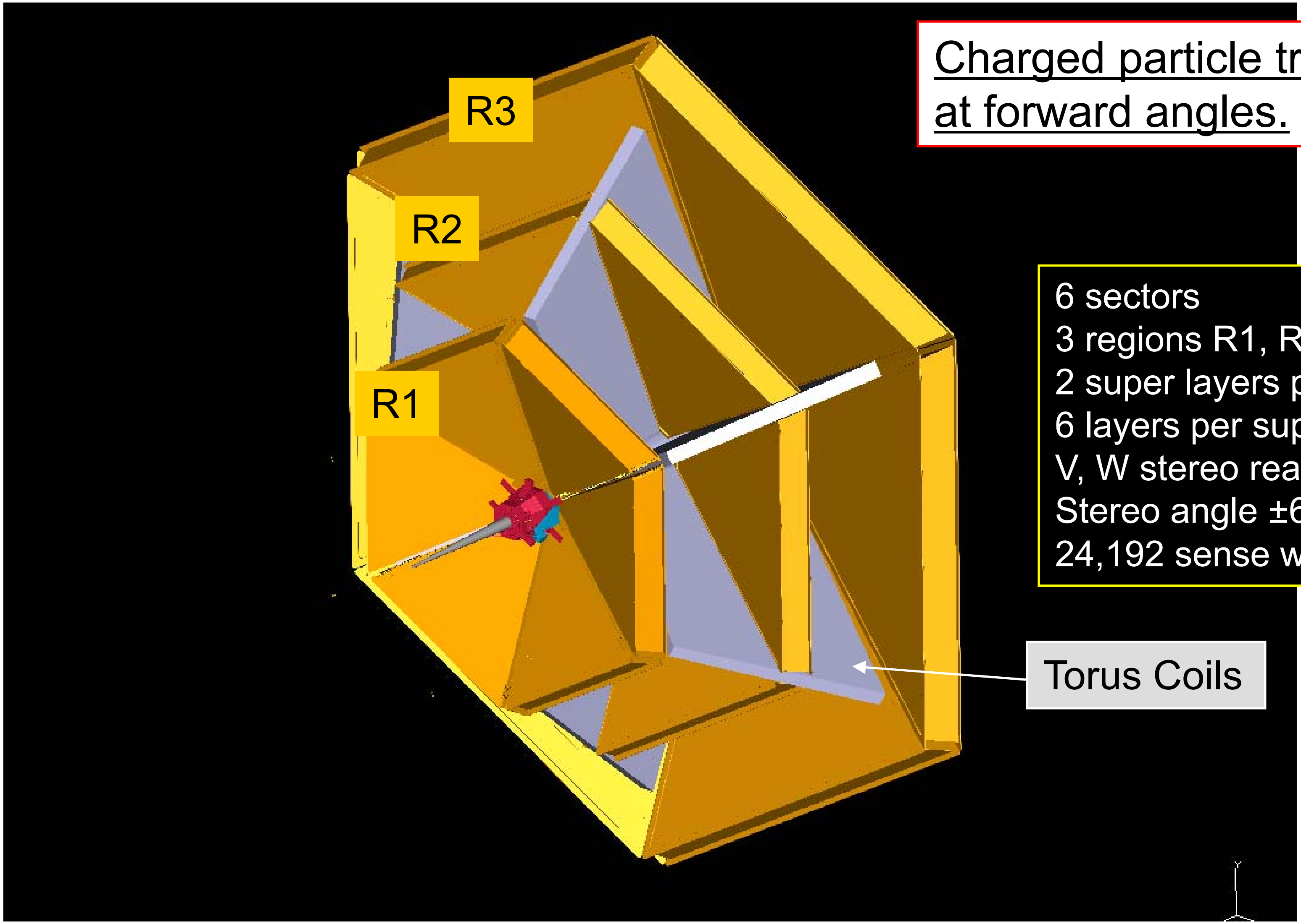
CLAS12 - High Threshold Cerenkov Counter (HTCC)



Electron identification up to 5GeV/c
π/K.p separation > 5 GeV/c
Level 1 Trigger

Radiator gas:	CO_2 @ 1 atm
π threshold:	4.9 GeV/c
π rejection:	200
# of PMTs (5”):	48
# sectors:	12
Mirror weight:	< 200mg/cm^2

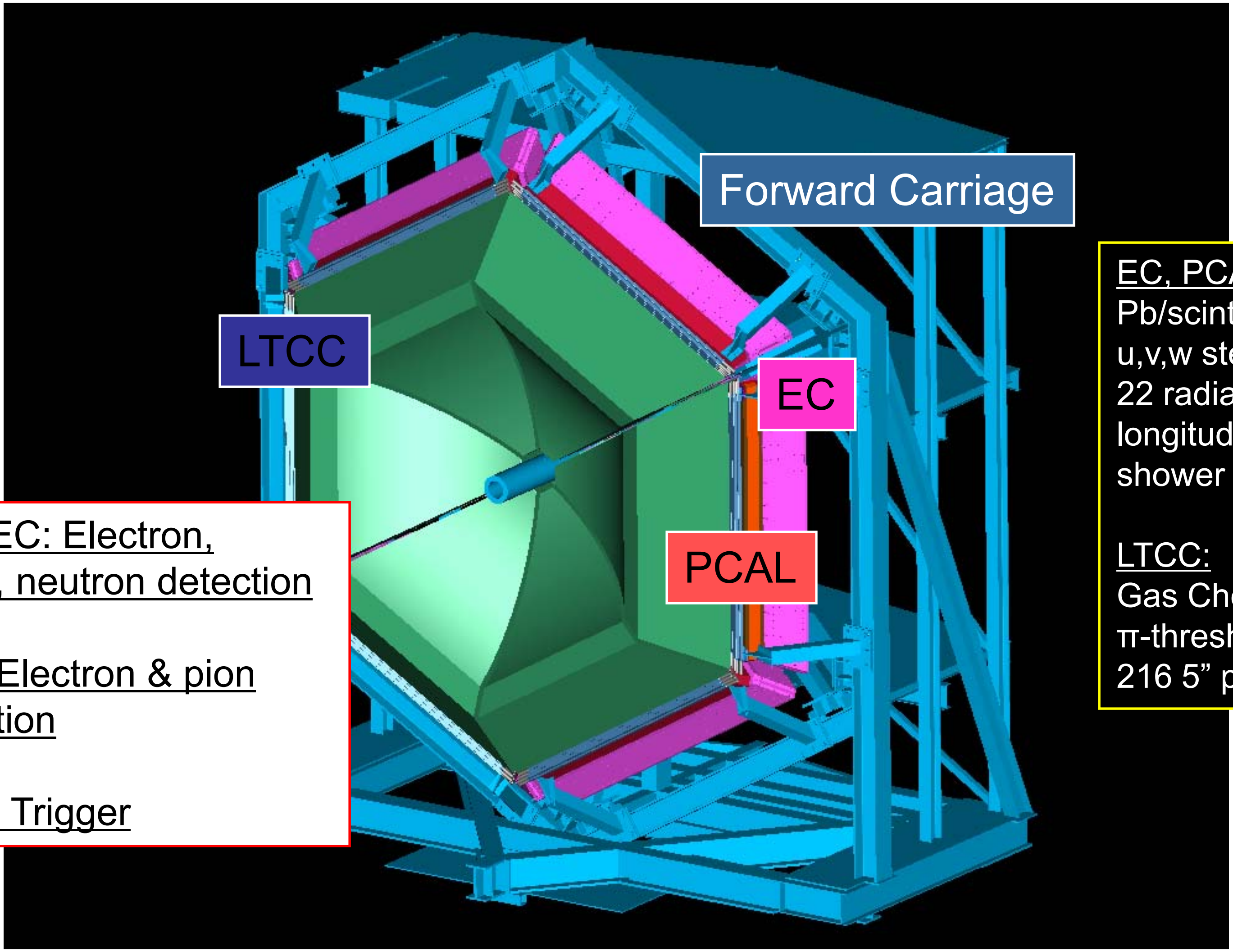
CLAS12 - Forward Drift Chambers



Charged particle tracking at forward angles.

- 6 sectors
- 3 regions R1, R2, R3
- 2 super layers per region
- 6 layers per super layer
- V, W stereo readout
- Stereo angle ±6 degrees
- 24,192 sense wires

CLAS12 - Forward Carriage



<u>PCAL/EC: Electron, photon, neutron detection</u>

<u>LTCC: Electron & pion separation</u>

<u>Level 1 Trigger</u>

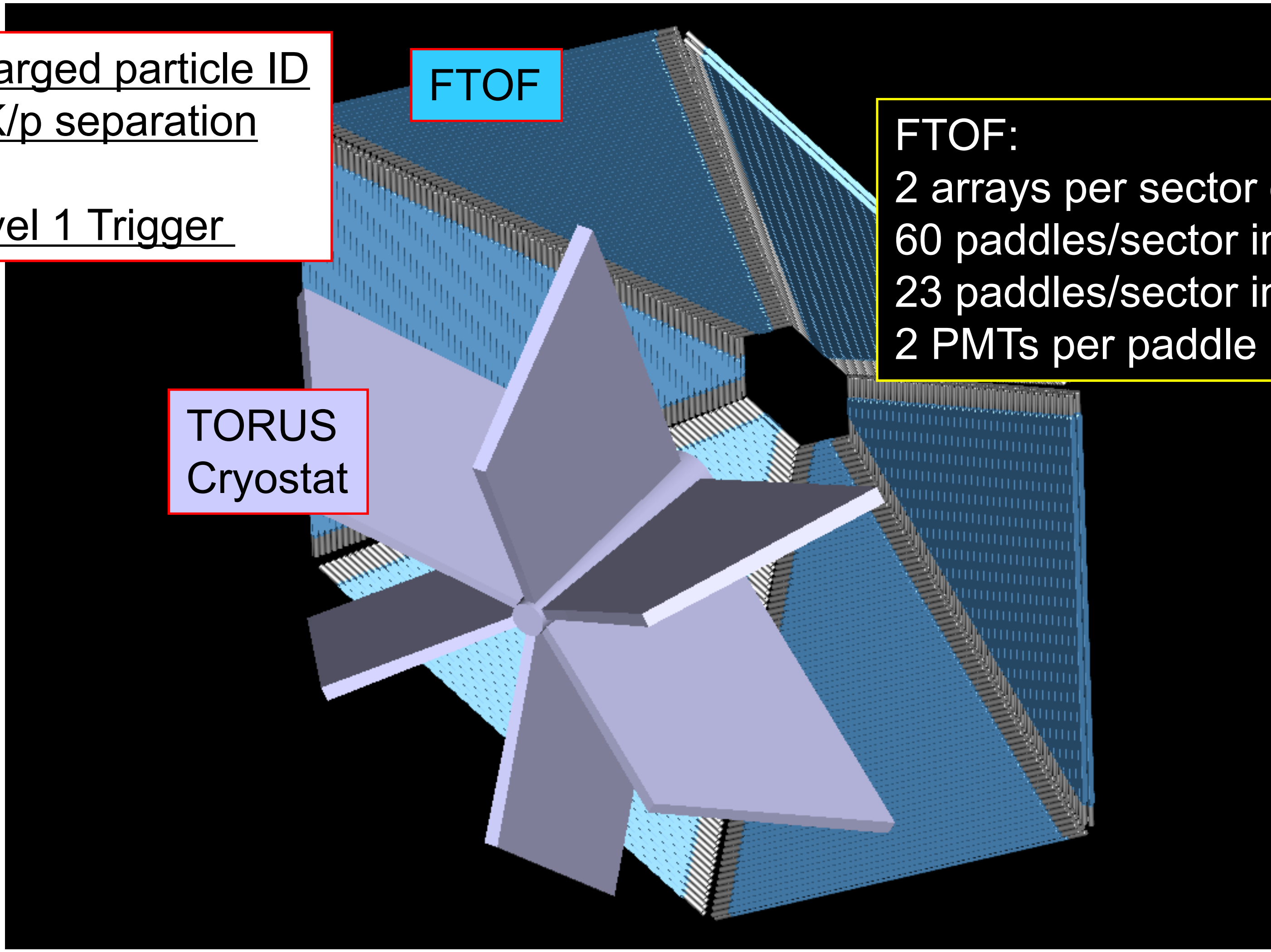
<u>EC, PCAL:</u>
Pb/scintillators sandwich
u,v,w stereo readout
22 radiation lengths
longitudinal/transverse shower sampling

<u>LTCC:</u>
Gas Cherenkov counter
π-threshold: 2.7 GeV/c
216 5” photomultipliers

CLAS12 - Forward TOF Counters

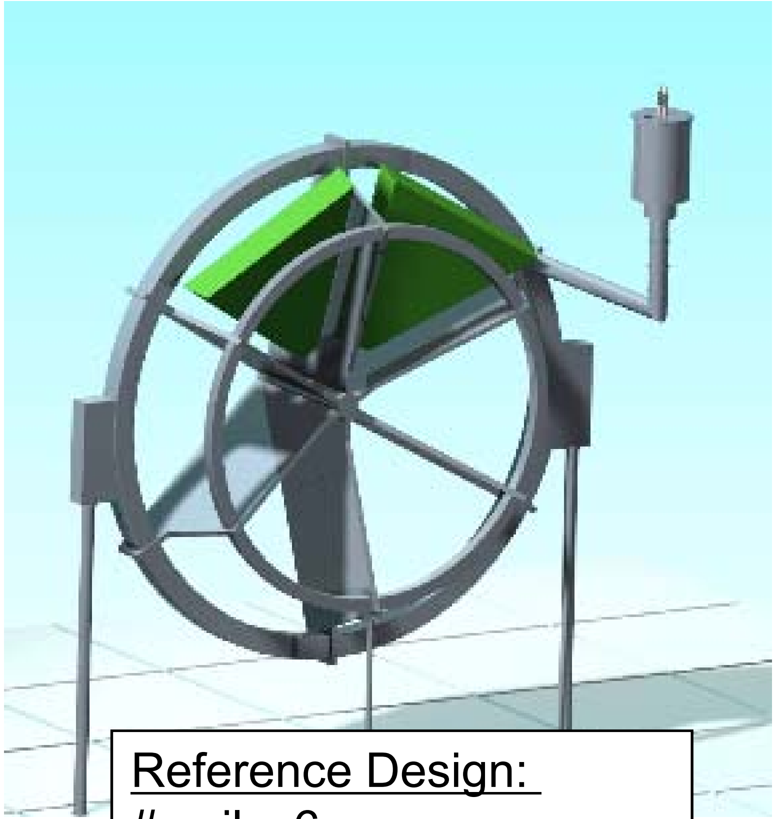
Charged particle ID
π/K/p separation

Level 1 Trigger

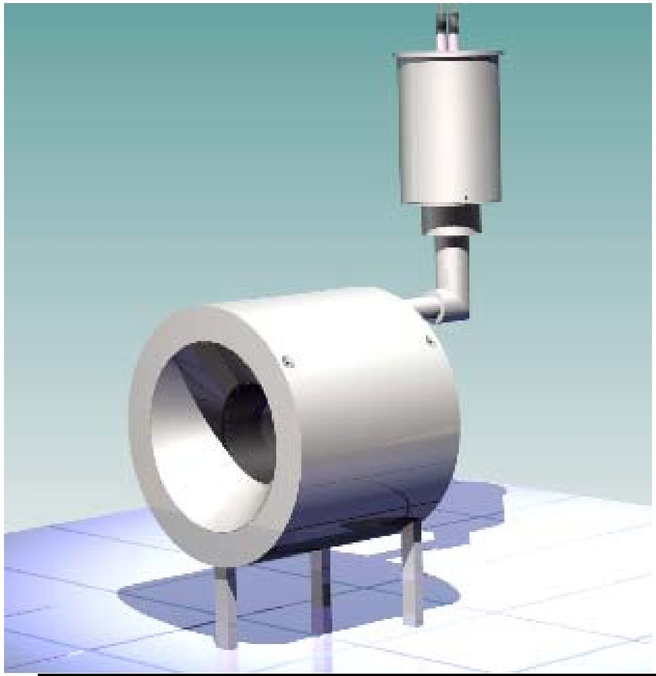


FTOF:
2 arrays per sector of scintillators
60 paddles/sector in array 1b (new)
23 paddles/sector in array 1a (existin
2 PMTs per paddle

Torus and Solenoid Magnets

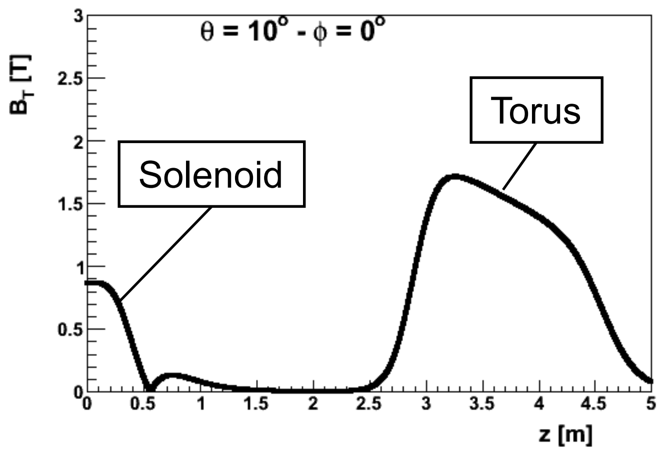


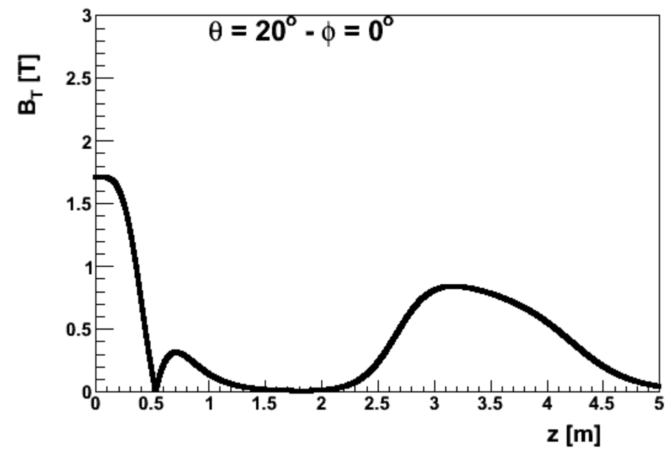
Reference Design:
coils: 6
Radial thickness: 294mm
Width: 100mm
Stored energy: 14MJ

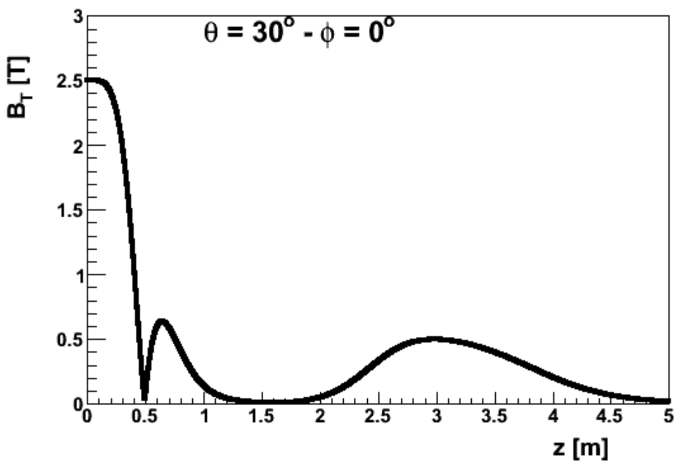


Reference Design:
Max. field: B=5 Tesla
Homogeneity: $\Delta B/B<10^{-4}$
Main coil windings: 4000
Shielding coil: 1880
Stored energy: 25 MJ

CLAS12 - Magnetic Field





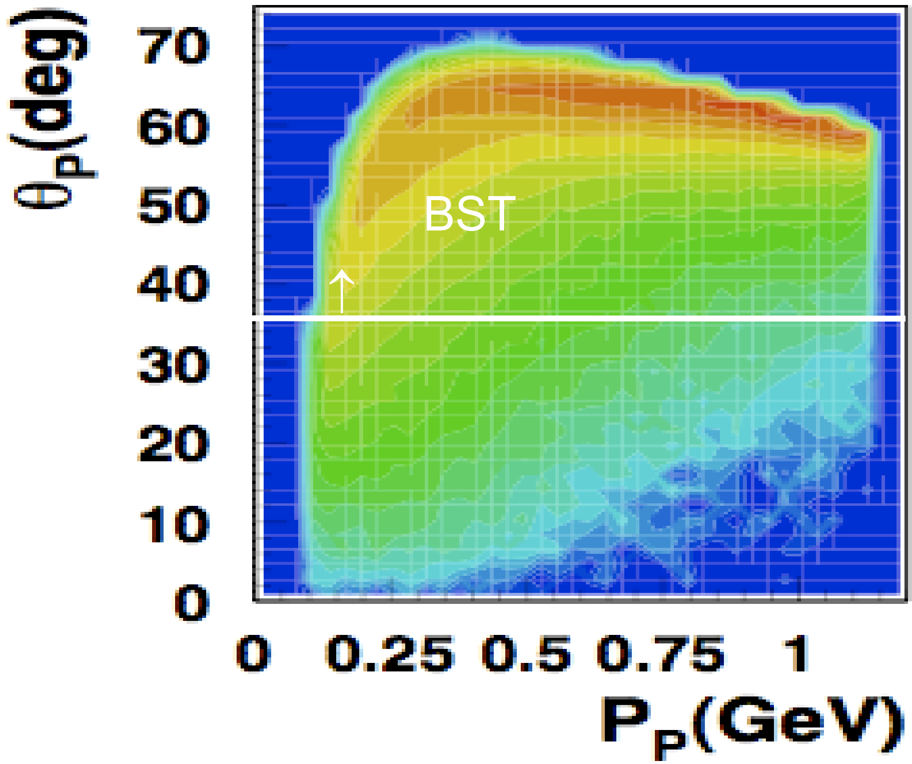


The Torus *transverse* field becomes weaker with increasing angle while the Solenoid *transverse* field component increases in strength.

CLAS12 - DVCS protons in BST

$ep \rightarrow ep\gamma$

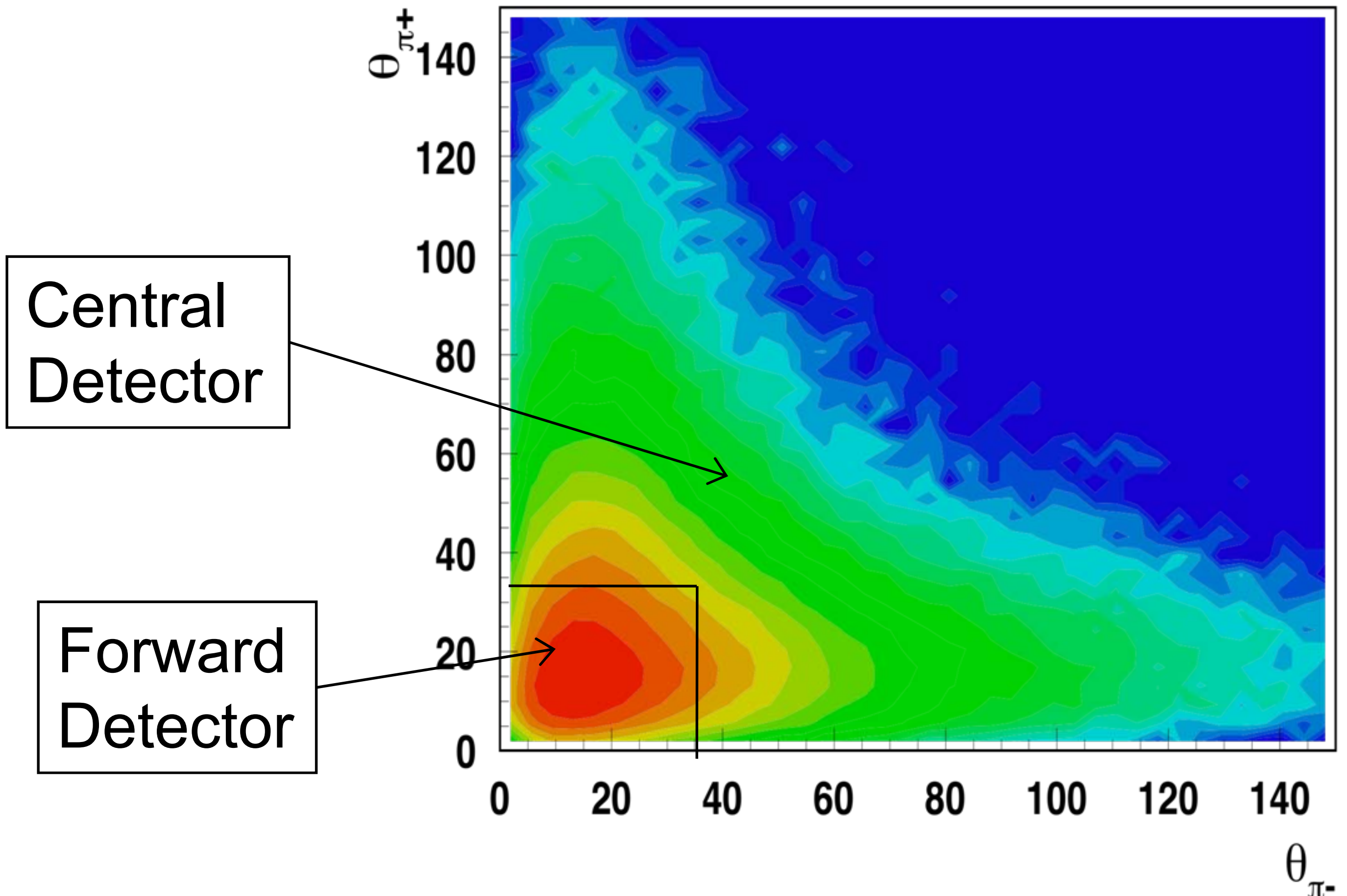
Measurement of Generalized Parton Distributions



Critical for tracking of recoil protons that occupy phase space at Lab angles greater than 35 degrees.

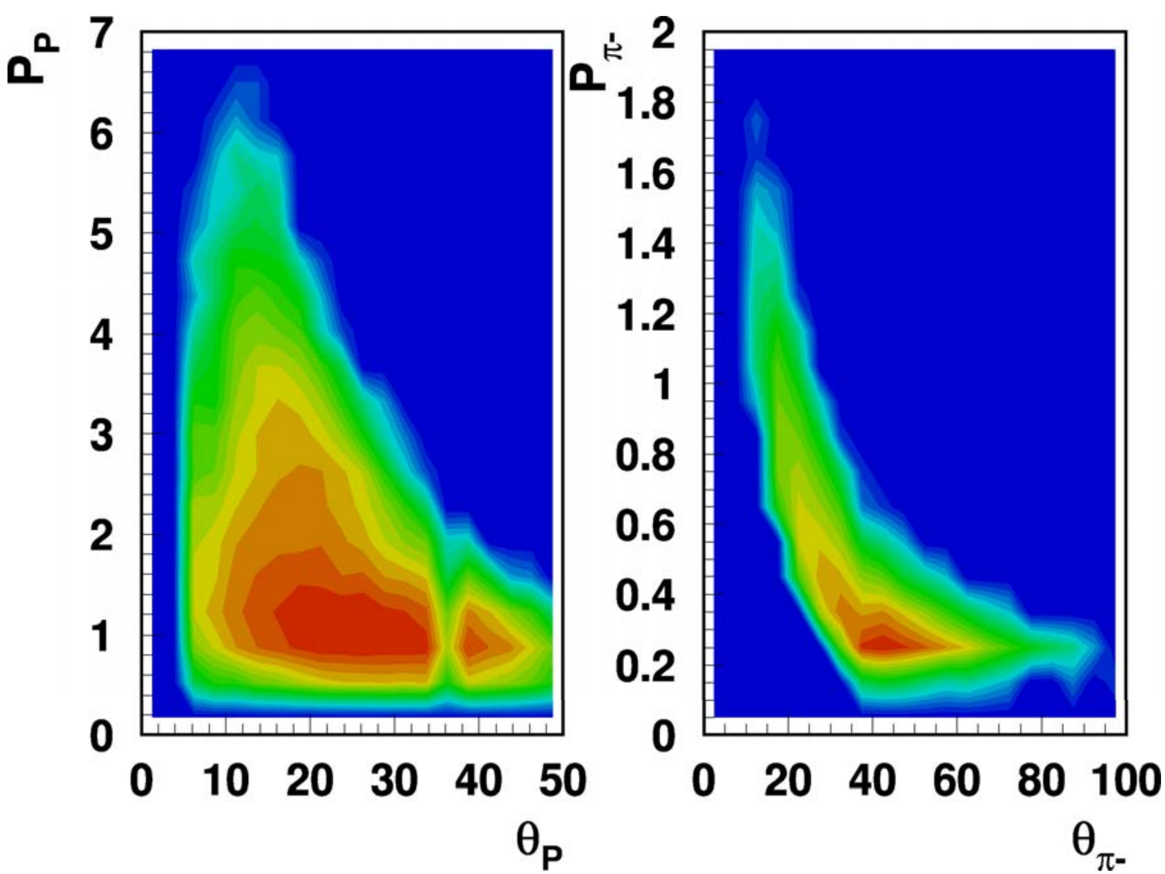
Kinematics for $ep \rightarrow eN^*(N^* \rightarrow p\pi^+\pi^-)$

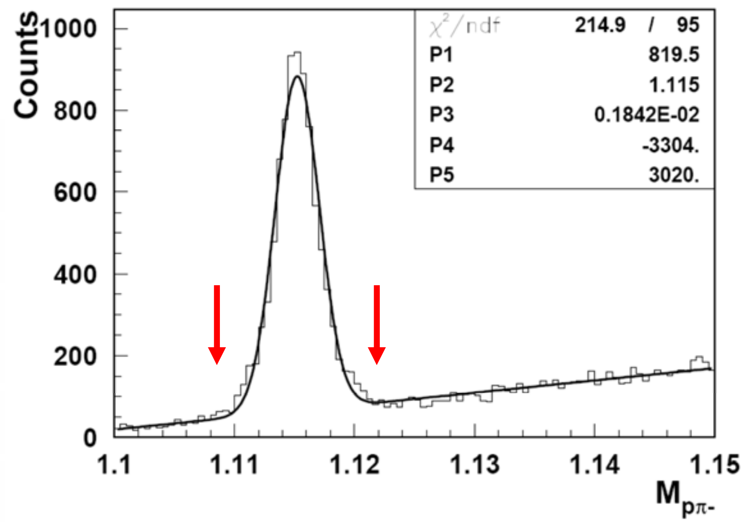
Measurement in full angular range needed for N* spectroscopy and partial wave analysis of final state hadrons.

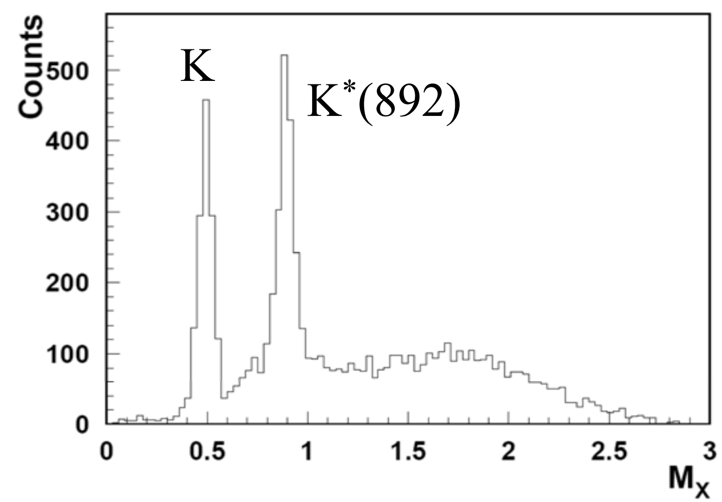


CLAS12 - Missing Mass Techniques

$$ep \rightarrow e\Lambda(p\pi^-)X$$







Rates & Background

CLAS12 - Electromagnetic Background

Low energy electromagnetic processes, especially Møller scattering of beam electrons off atomic electrons are the main contributor to the background load in an open large acceptance spectrometer such as ***CLAS12***.

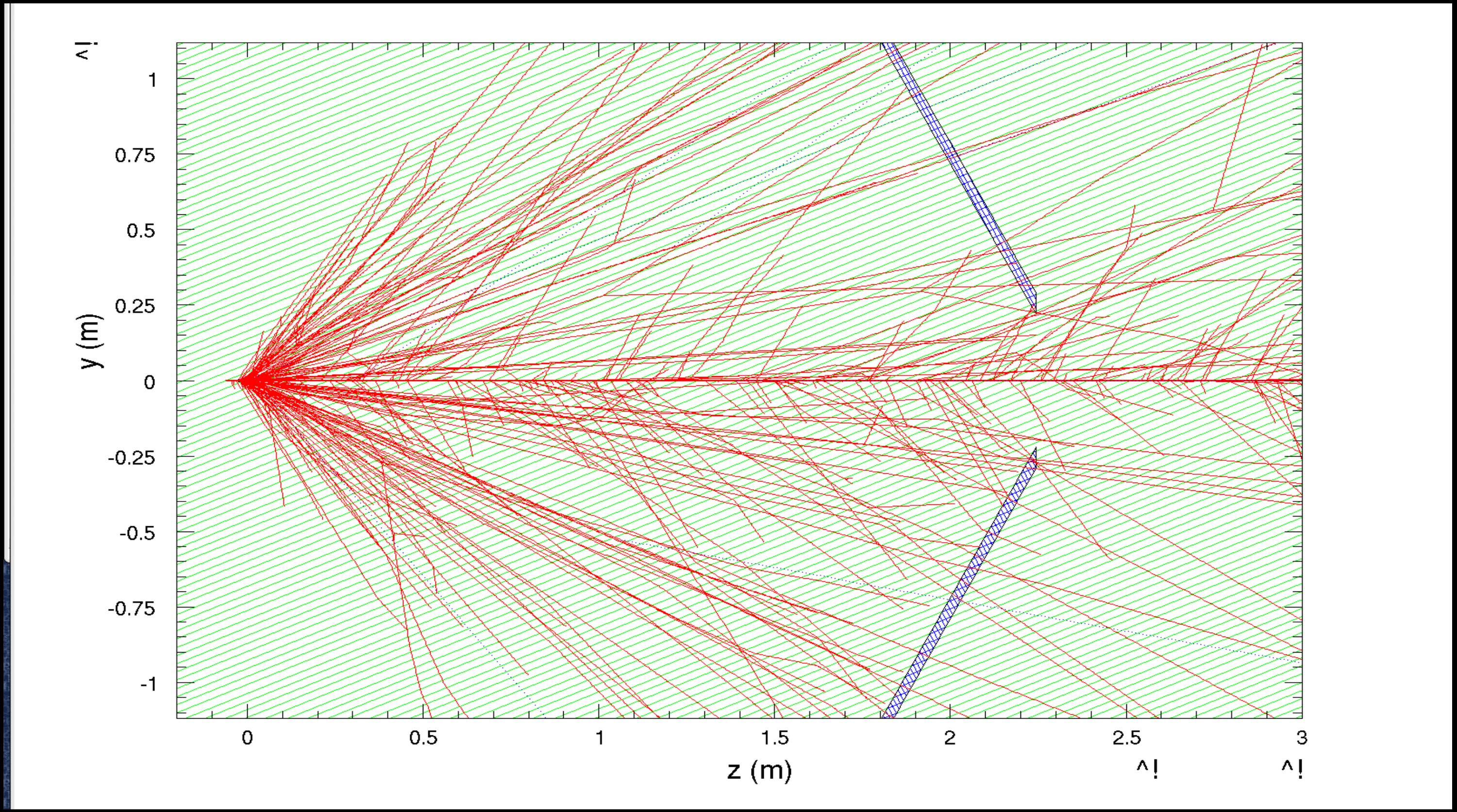
The full event and background load has been measured with CLAS, e.g. for DVCS process at 5.7 GeV. The GEANT simulation reproduces hit occupancy on tracking chambers.

We used the calibrated simulation code to extrapolate to 11 GeV and simulate the same process at higher luminosity for CLAS12 situation.

This background was also studied in a full Geant4 simulation.

CLAS12

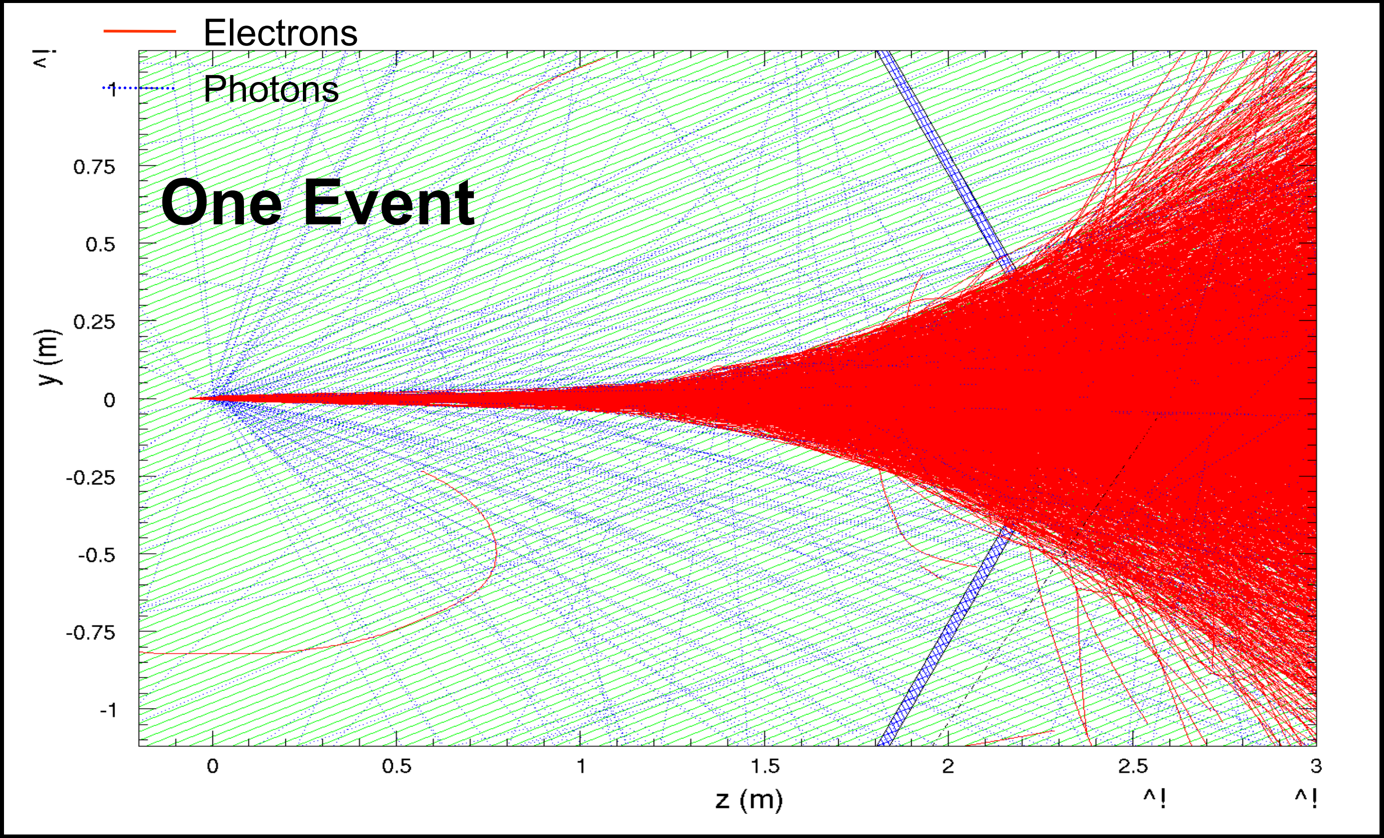
Background at L=10^{32}cm^{-2}s^{-1}, ΔT = 150ns



No magnetic field

CLAS12

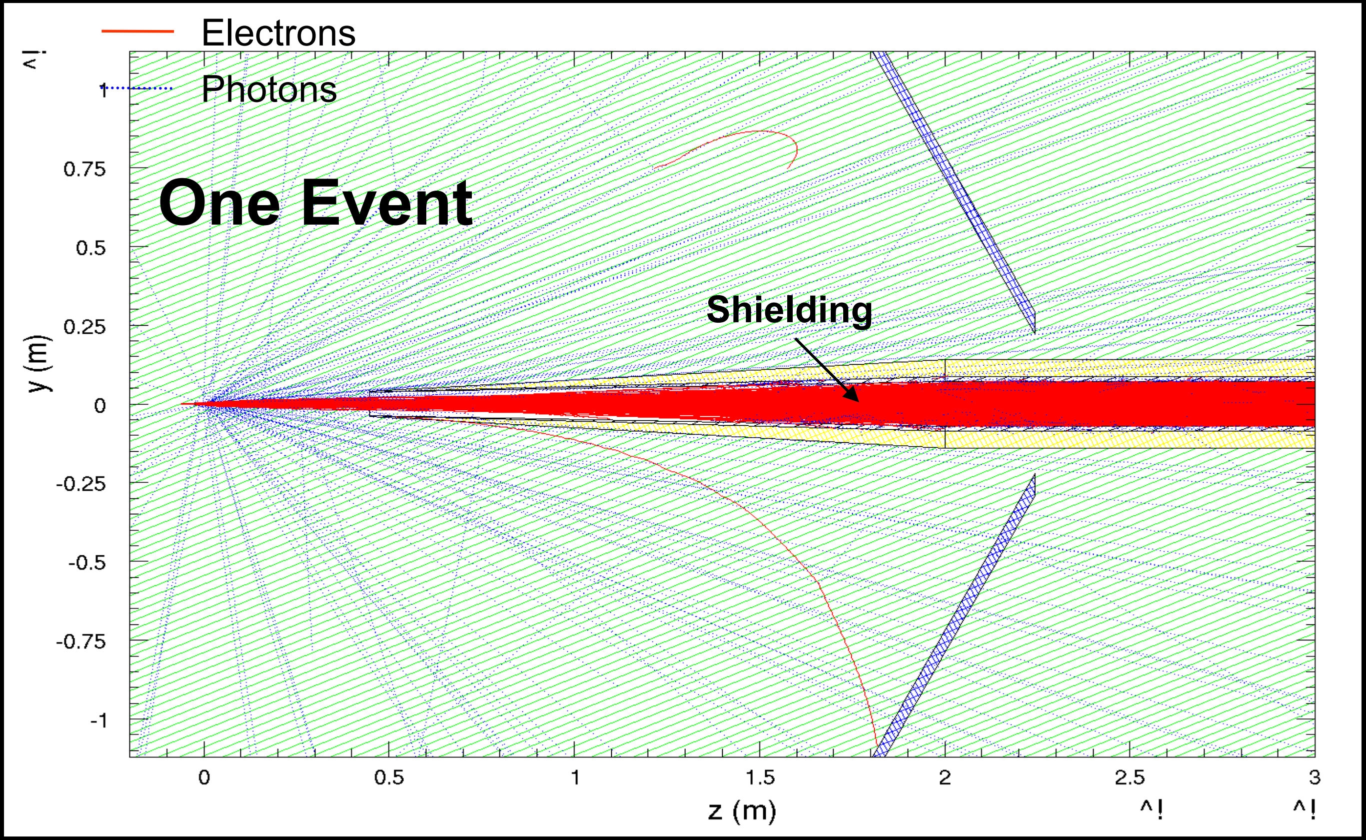
Background at $L=10^{35}cm^{-2}s^{-1}$, ΔT = 150ns



5 T Magnetic Field

CLAS12

Background at $L=10^{35}cm^{-2}s^{-1}$, ΔT = 150ns



5 T Magnetic Field and Shielding

CLAS12 – Expected Rates in DC R1

	CLAS	CLAS12
Energy	**5.75**	**11**
Luminosity ($cm^{-2}s^{-1}$)	**$2x10^{34}$**	**10^{35}**
Total rate	5.94	5.76
Electrons from γ's	**0.74**	**1.7**
Scattered electrons	**4.65**	**1.0**
Hadrons	**0.55**	**3.06**

CLAS12 - Event rates & multiplicities

- **Simulations show that typical deep inelastic events contain**
  - **3.5 charged particles per event at $\theta < 35^o$ (Forward Detector)**
  - **0.75 charged particles at $\theta > 35^o$ (Central Detector)**

- **The total hadronic interaction rate is ~$5x10^6$ sec^{-1}**

- **Expected level 1 trigger rate is up to 10KHz (inclusive electron rate ~4KHz, non-electron triggers ~5KHz)**

- **Expected data rate is 50-80Mbsec^{-1} for beam energies from 6.6 to 11 GeV.**

CLAS12 - Event reconstruction

- **A full event reconstruction is available for CLAS detectors that has been used to aid the R&D and design effort for** *CLAS12.*

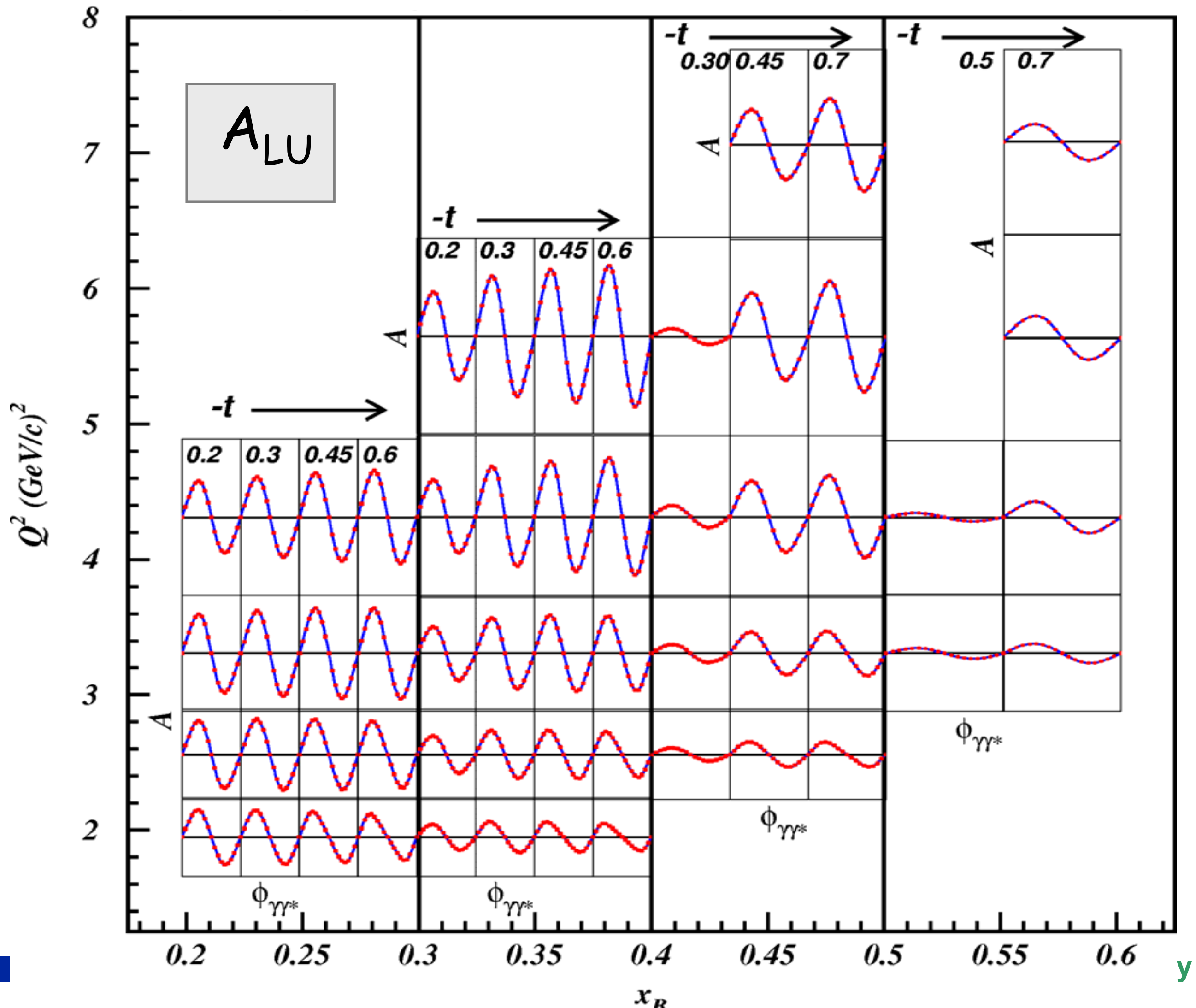
- **The collaboration is developing new simulation and reconstruction software packages making use of modern tools.**

Hall B Upgrade Summary

- **The physics program allows to firmly establish requirements for the** *CLAS12* **performance in terms of rate capability, particle ID, and resolution.**
- **At 12 GeV typical events contain high momentum tracks at forward angles. The toroidal magnetic field of** *CLAS12* **and the forward tracking system provide excellent angle and momentum reconstruction.**
- **Essential parts of the physics program require tracking of low momentum at large angles. This is achieved by the Silicon Tracker.**
- **The increase in luminosity is achieved by improved background shielding and high rate capability of the tracking devices.**
- **The new Cerenkov and Scintillation counters in** *CLAS12* **are designed to improve particle separation at higher momentum.**
- **An experienced team is in place that built, installed, commissioned and operates CLAS, and collaboration members have taken on responsibilities for the construction of new detector components, and for state-of-the art event simulation and reconstruction.**

DVCS/BH- Beam Asymmetry

$E_e = 11\ GeV$



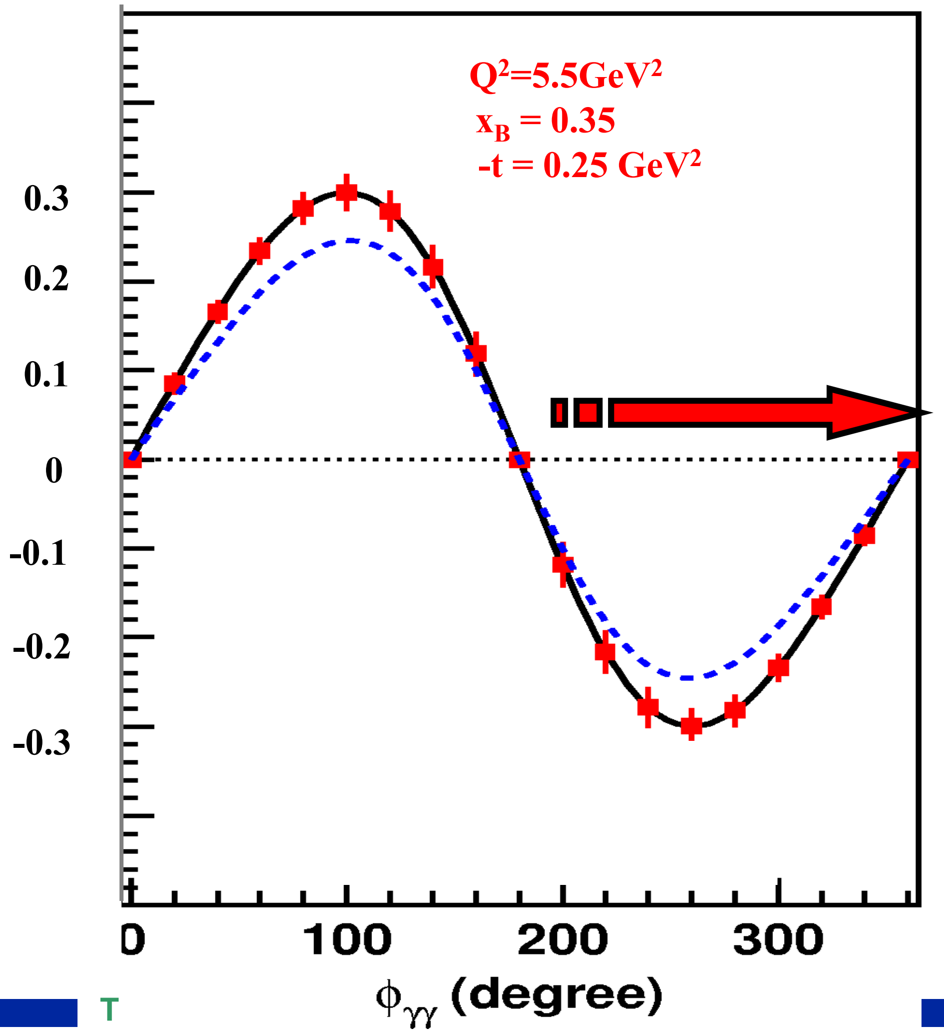
With large acceptance, measure large Q^2, x_B, t ranges simultaneously.

$A(Q^2,x_B,t)$
$\Delta\sigma(Q^2,x_B,t)$
$\sigma\ (Q^2,x_B,t)$

CLASS12 - DVCS/BH- Beam Asymmetry

Luminosity = 720fb^{-1}

E_e = 11 GeV



T

CLAS12 - DVCS/BH Beam Asymmetry

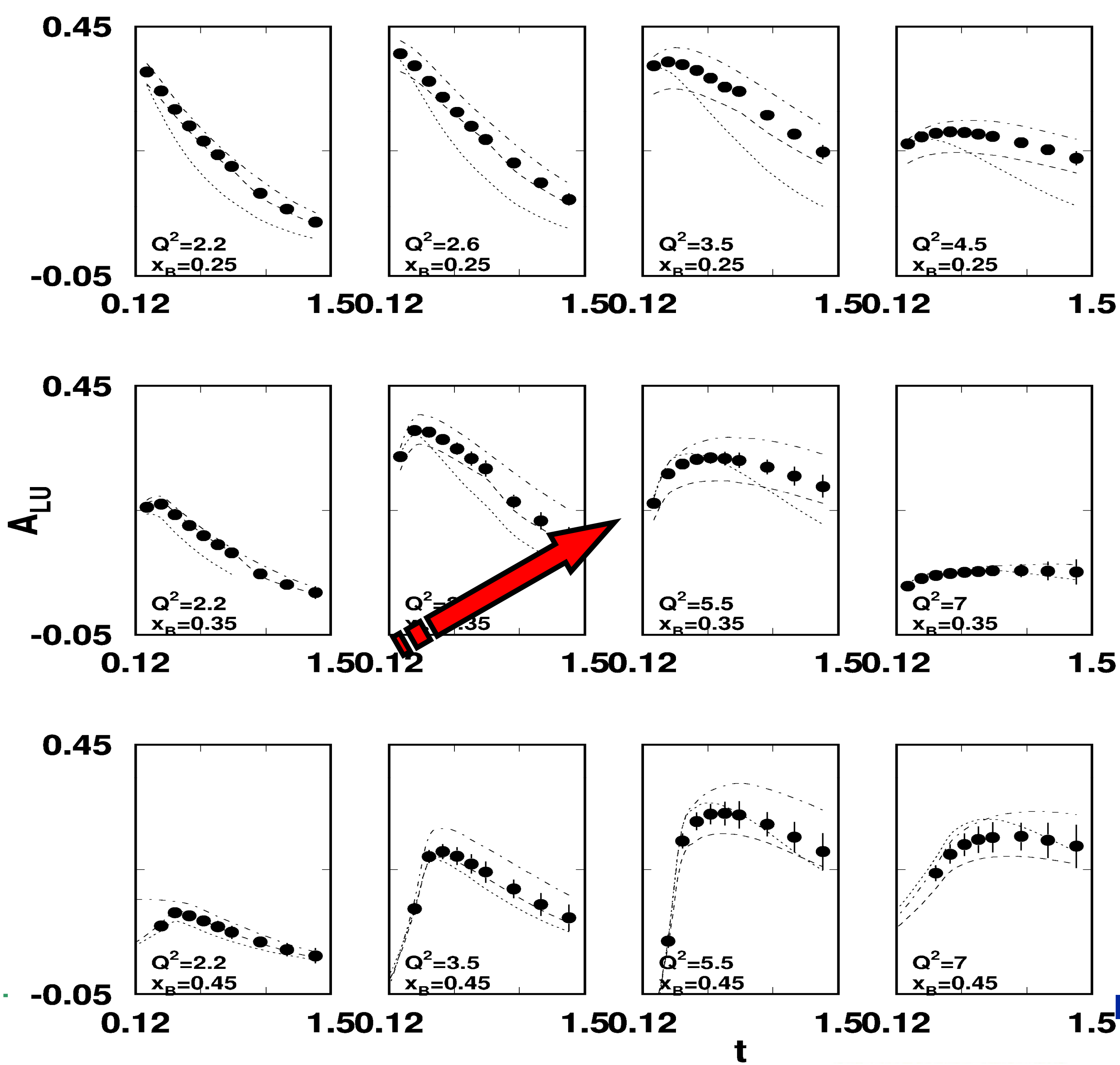
$\vec{e}\,p \longrightarrow ep\gamma$

E = 11 GeV

$\Delta\sigma_{LU} \sim \sin\phi\,\mathrm{Im}\{F_1\mathcal{H}+..\}d\phi$

Selected Kinematics

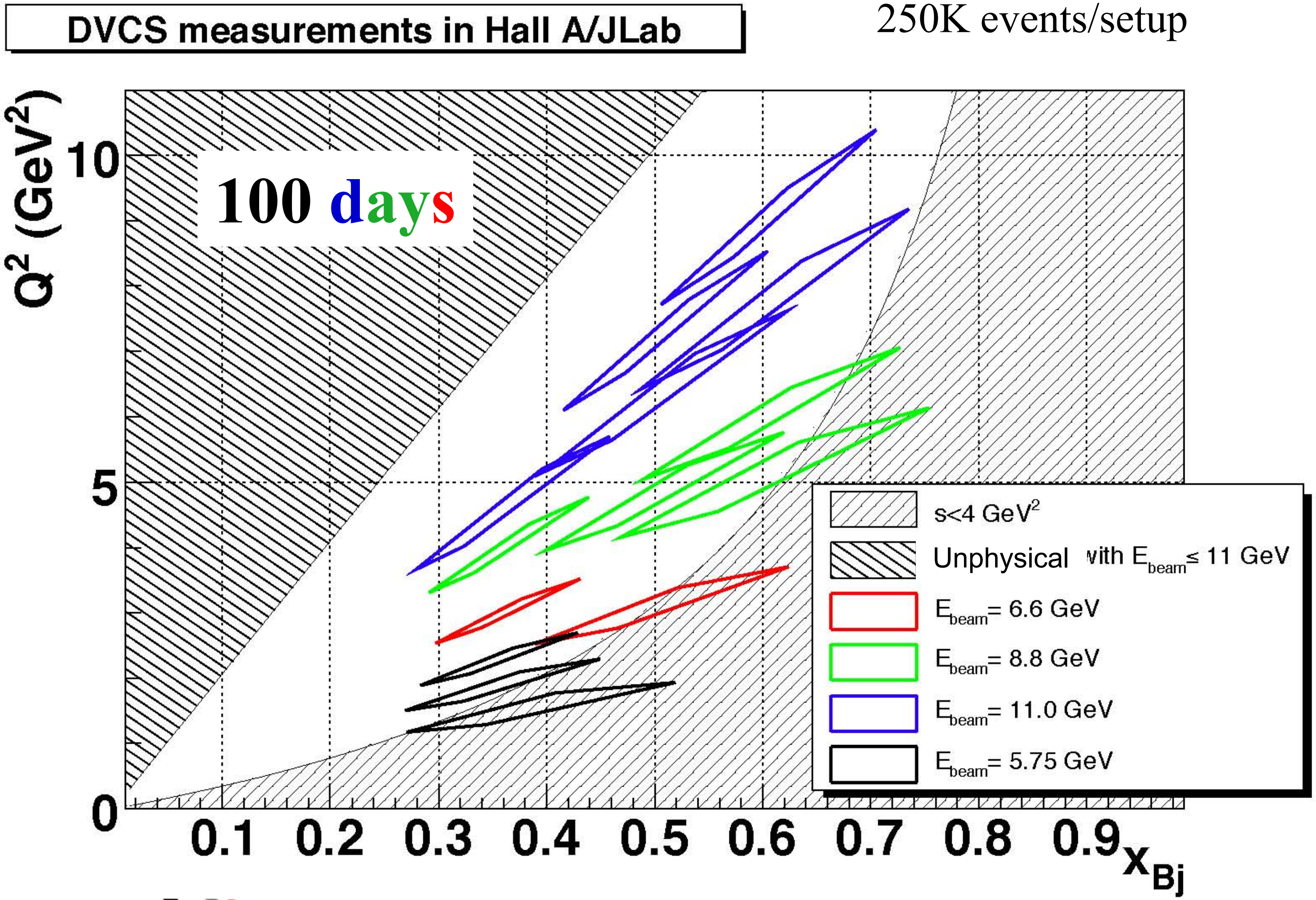
$L = 1\mathrm{x}10^{35}$
$T = 2000$ hrs
$\Delta Q^2 = 1\ \mathrm{GeV}^2$
$\Delta x = 0.05$



JLab12: Hall A with 3, 4, 5 pass beam

H(e,e'γ)p

High luminosity → high accuracy
Absolute measurements: $d\sigma(\lambda_e=\pm 1)$
250K events/setup



Twist 2 & Twist 3 separation

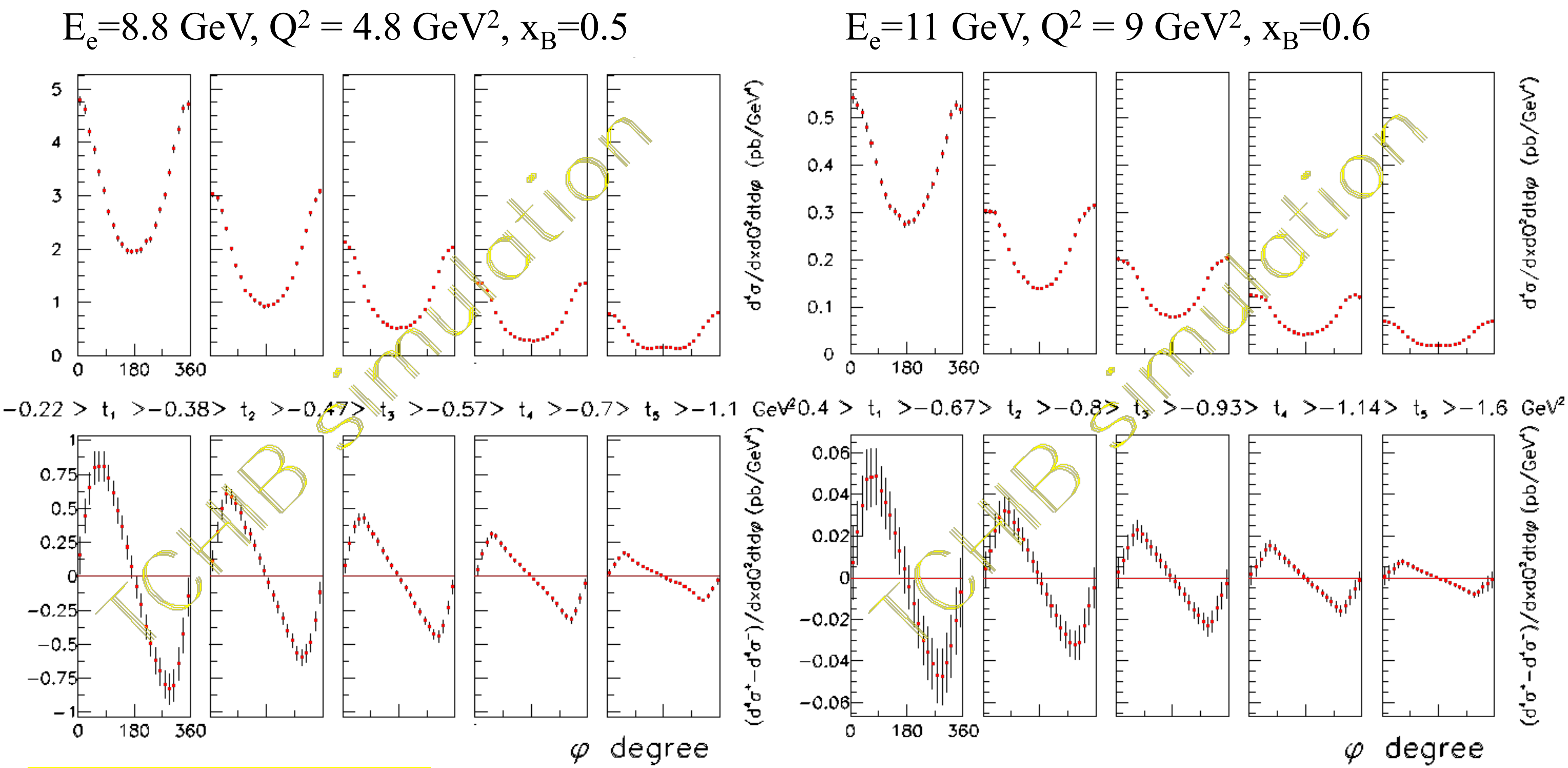
Im{DVCS*BH} +εDVCS^2

Re{DVCS*BH} +ε'DVCS^2

JLab12: projected results for DVCS in Hall A

Unpolarized cross sections (pb/GeV⁴)

400 hours



…and exclusive π^0 electroproduction will also be measured

Polarized cross section differences (pb/GeV⁴)

C. Hyde-Wright et al., arXiv:nucl-ex/0609015

CLAS12 - DVCS/BH Target Asymmetry

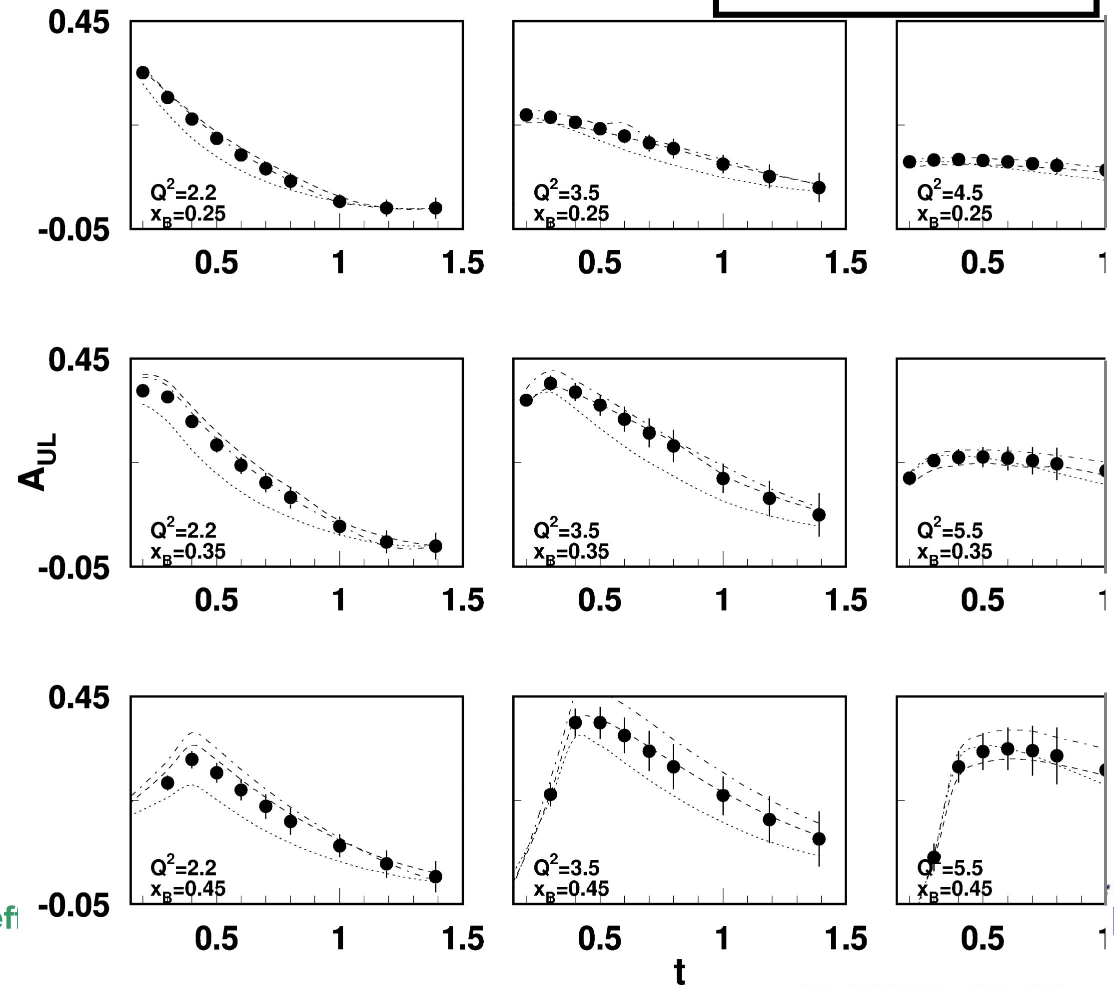
$$e\,\vec{p} \longrightarrow e p \gamma$$

E = 11 GeV

L = 2x10^{35} cm^{-2}s^{-1}
T = 1000 hrs
ΔQ^2 = 1GeV^2
Δx = 0.05

Longitudinally polarized target

$$\Delta\sigma \sim \sin\phi \, \mathrm{Im}\{F_1\widetilde{H} + \xi(F_1+F_2)H \ldots\}d\phi$$



CLAS12 - DVCS/BH Target Asymmetry

$e\ p^{\uparrow} \longrightarrow e p \gamma$

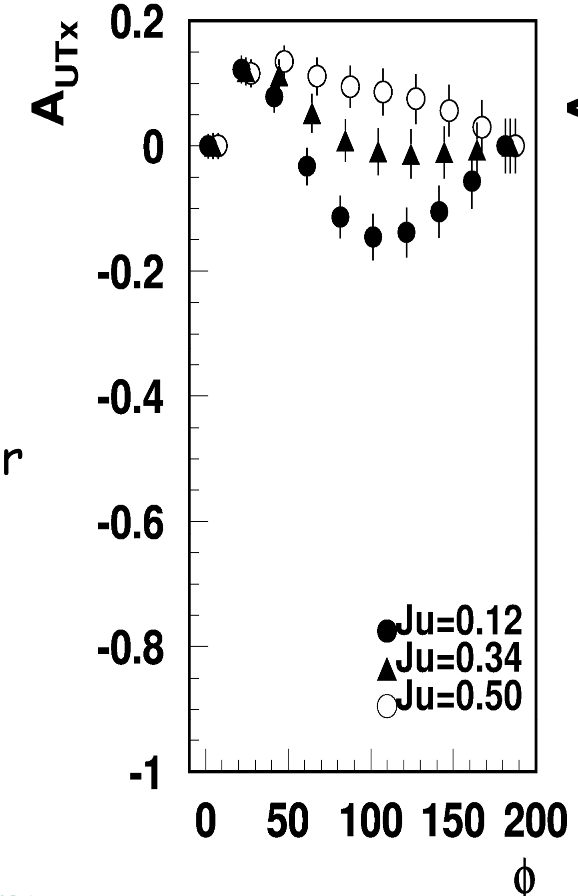
E = 11 GeV

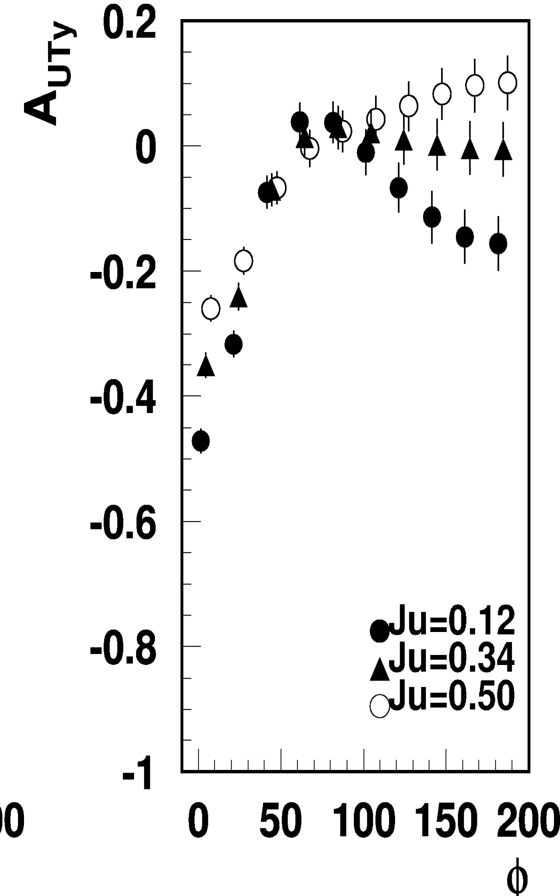
Sample kinematics

Q^2=2.2 GeV^2, x_B = 0.25, -t = 0.5GeV^2

Transverse polarized target

$\Delta\sigma \sim \sin\phi \, \mathrm{Im}\{k_1(F_2 \mathcal{H} - F_1 \mathcal{E}) + \ldots\} d\phi$





A_{UTx} Target polarization in the scattering plane

A_{UTy} Target polarized perpendicular to the scattering plane

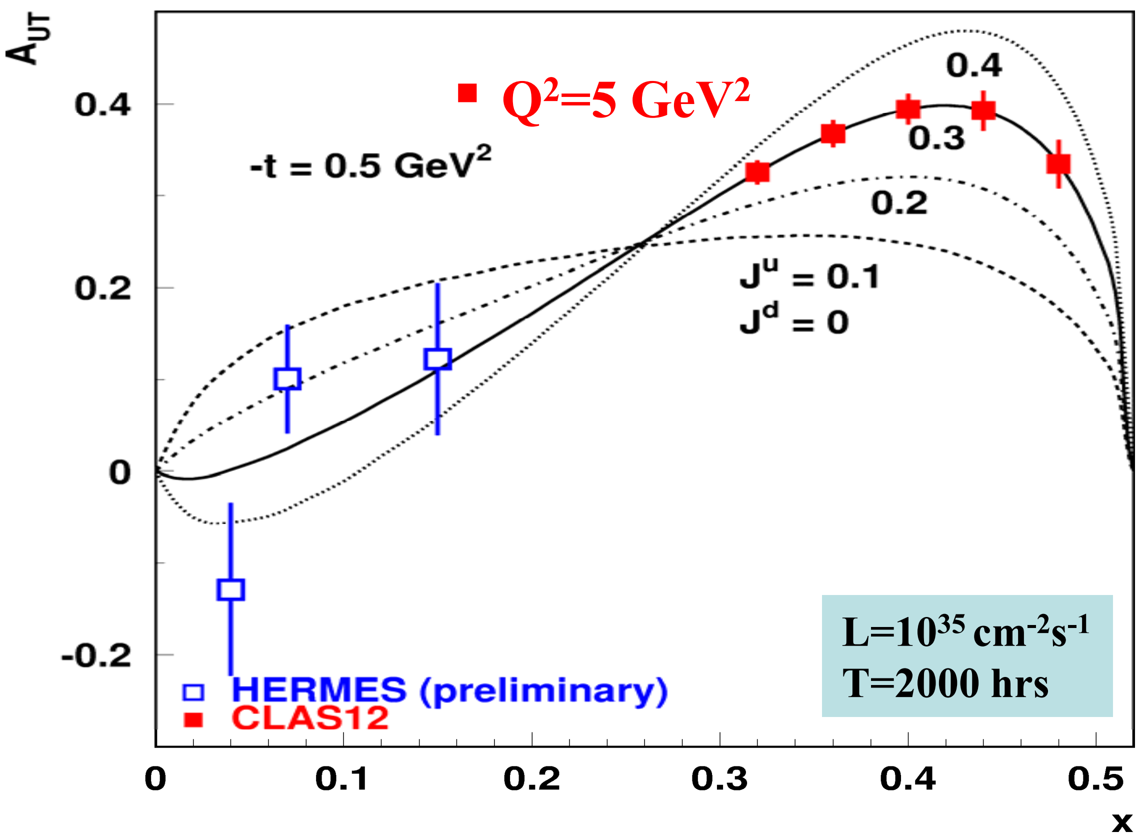
- *Asymmetries are highly sensitive to the u-quark contributions to the proton spin.*

CLAS12: $ep^{\uparrow} \rightarrow ep\rho^0$

$$A_{UT} = -\frac{2\Delta_{\perp}(\mathrm{Im}(AB^*))/\pi}{|A|^2(1-\xi^2) - |B|^2(\xi^2+t/4m^2) - \mathrm{Re}(AB^*)2\xi^2}$$

ρ^0

$A \sim (2H^u + H^d)$
$B \sim (2E^u + E^d)$

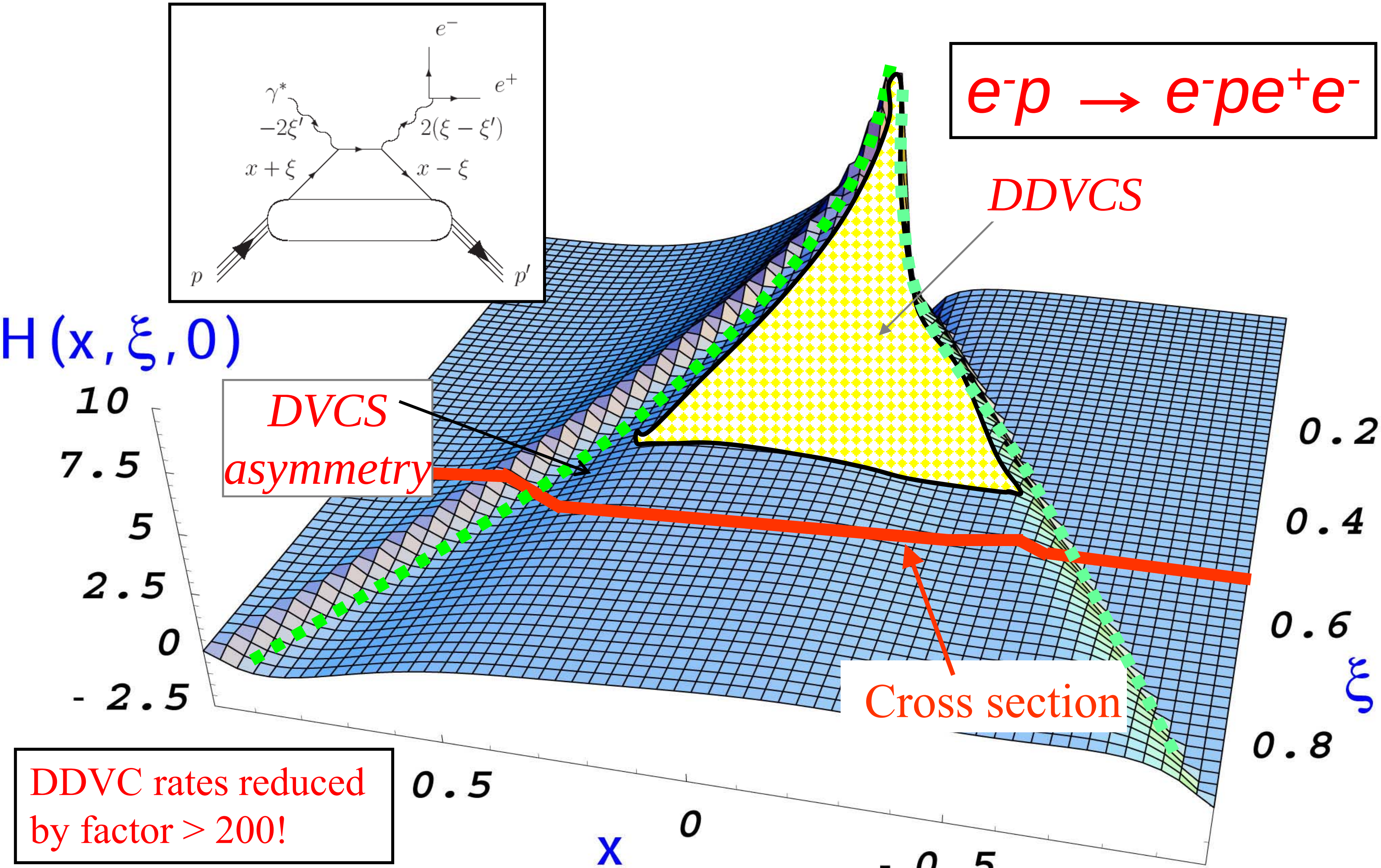


Asymmetry depends on the GPD E, necessary for Ji's sum rule

Goeke, Polyakov, Vanderhaegen (2001)

…and CLAS12 will allow us to measure also DVCS polarized and unpolarized cross sections, nDVCS, vector and pseudo-scalar meson electroproduction…

Double DVCS (DDVCS)



DDVC rates reduced by factor > 200!

Conclusions

- We have come a long way in studying the structure of the proton since Hofstadter's pioneering experiments more than 50 years ago.
- With QCD as the theoretical framework, and the handbag mechanism and GPDs as tools the proton (and neutron) structure can be accessed systematically.
- First experiments demonstrate the applicability of the basic "handbag" mechanism at moderate (Jlab) energies.
- The JLab energy upgrade and new equipment provide the means to explore the complex proton structure in the full valence quark regime.

Conclusions

- Deeply virtual exclusive processes have been shown to reveal novel information on the *structure* of nucleons.
- First results on *DVCS* (and DVMP) show the feasibility of the measurements, and seem consistent with the handbag approximation.
- First dedicated DVCS high precision experiments at JLab have either been completed, are underway, or planned for 2007/2008. They will give precise *direct* information on several GPDs in limited kinematics
- The JLab 12 GeV energy upgrade with new instrumentation (CLAS12) will provide ideal conditions for an extensive program to measure deeply virtual exclusive processes in a broad kinematics regime.

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